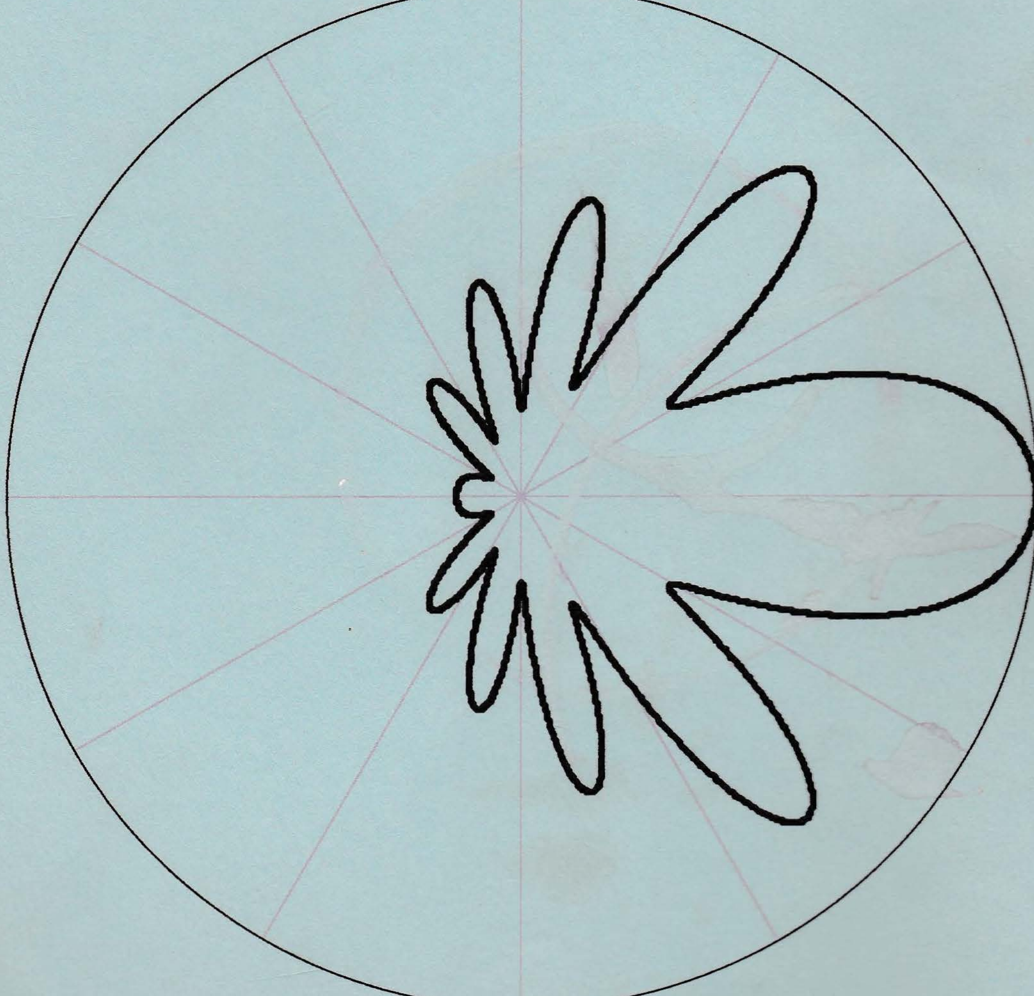
THE BEVERAGE ANTENNA HANDBOOK



Victor A. Misek, P.E.
W1WCR

THIRD EDITION

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1 INTRODUCTION TO BEVERAGE ANTENNAS

The Beverage Antenna is a directional receiving antenna named after Harold H. Beverage, who discovered the directional properties of long wire ground antennas. Beverage referred to his antennas as WAVE ANTENNAS, a term I use in this book. The pioneering work done by Beverage, Rice and Kellogg was published in a paper titled THE WAVE ANTENNA appearing in the February, 1923 TRANSACTIONS OF THE A.I.E.E.

Wave antennas have been popular in the following applications:

1. Improving the reception of DX signals.
2. Rejecting broadcast stations in the amateur bands.
3. Static reduction.
4. Rejection of power line noise, TV birdies and locally generated noises.
5. Short wave listening.

Two forms of the wave antenna are used in high frequency communications. The simplest of these is a horizontal straight wire typically a half wave or more in length terminated in its characteristic impedance. This is the familiar SINGLE WIRE BEVERAGE noted for its unidirectional properties and widely used to work DX on the 160 and 80 meter amateur bands. I have established criteria for optimizing the front-to-back ratio of these antennas by optimizing the length. I call the resulting operation the CONE OF SILENCE MODE.

The other form of the wave antenna is the STEERABLE WAVE ANTENNA or SWA which is sometimes referred to as the TWO WIRE BEVERAGE. This is the most desirable form of the wave antenna because it features:

1. Directivity switchable in opposite directions.
2. An electrically steerable null, hence the name steerable wave antenna.
3. Center or end-fed options.

In effect, the SWA is equivalent to two single wire antennas aimed in opposite directions, but occupying the same physical space. The single wire Beverage is restricted to an end-fed configuration. The SWA may be center-fed, end-fed or even off-center-fed resulting in savings in feeder length and avoiding running coaxial cable in unwelcome places.

Since the publication of the first edition of this handbook on 1977 I have talked with many people whose interest in Beverage antennas is limited by the dimensions of their properties, a particularly severe problem in urban areas. Accordingly, I have researched and developed highly shortened SWA designs which appear in this book as the MICRO-SWA and the MICRO-SLO.

The directivity of the Beverage drops rapidly as the length decreases below a half wave. My research indicates that the directivity of a short SWA (even as short as one tenth wavelength) can be restored to virtually the same directivity as a half wave SWA by utilizing NULL STEERING circuitry. Operating a short SWA (much under a half wave) with null steering causes a great deal of signal

cancellation, thus trading off signal level for the benefit of noise reduction in an environment of high electrical noise. The signal cancellation may be off-set by utilizing a low noise figure pre-amplifier or by constructing a slow-wave antenna.

The Beverage antennas described in this book are matched to coaxial cable using small ferrite core r-f transformers. The core materials have improved over the years and have resulted in changes in the recommended ferrite cores. The cores are often difficult to obtain in small quantities, so I sell ferrite cores to make construction easier. When improved core materials have appeared I have provided update sheets to core purchasers as part of the purchase transaction. The core purchase information at the end of this book may thus change and be updated in the future.

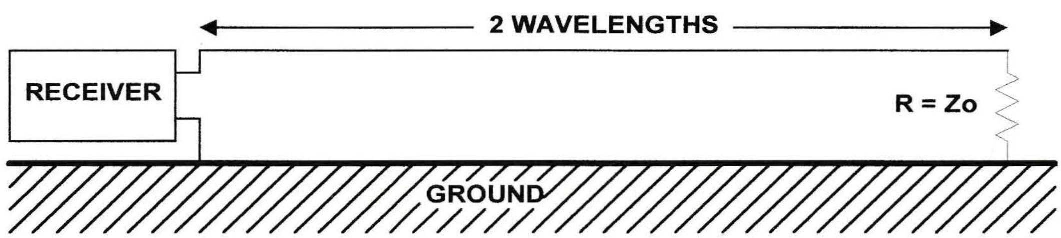


Figure 1
Single wire wave antenna

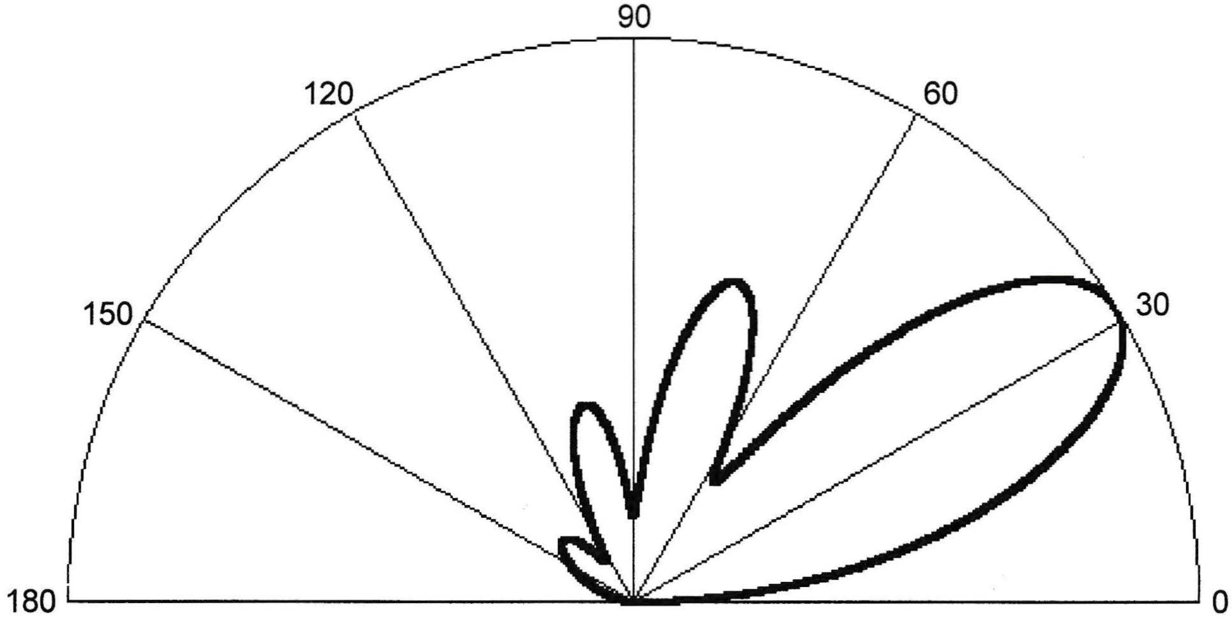


Figure 2
Elevation radiation pattern for antenna shown in fig. 1.

2 THE SINGLE WIRE WAVE ANTENNA

A diagram of a basic single wire wave antenna is shown in figure 1. Basically it consists of a long straight wire terminated at its far end in a resistance equal to the characteristic impedance (Zo) of the wire. Because of its matched termination the antenna is non-resonant (aperiodic). Electrically it behaves like a matched transmission line, thus the input impedance is constant over a very wide frequency range. A broadband r-f transformer can be used to match the antenna to a receiver without the need for tuning devices. The impedance of the antenna is determined by wire diameter, height above ground, and ground conditions. The impedance increases with increasing antenna height and decreasing wire diameter.

The wave antenna shown in figure 1 might have a practical length ranging from .5 wave to several wavelengths. It should be kept in mind that while the impedance remains constant with respect to frequency, the radiation pattern varies substantially. The elevation pattern of the 2 wavelength example is shown in figure 2. The free space pattern would be formed by rotating the pattern of figure 2 about the wire. Because the antenna is close to ground (height usually less than .1 wave) the pattern approaches zero as it is rotated parallel to ground. The pattern of figure 2 is therefore just one cross-section of the solid spatial pattern, but it contains the peak values of the lobes. The elevation pattern has one lobe per half wave or fraction thereof. A .6 wave antenna would therefore have two lobes.

In order to acheive the pattern of figure 2 the wire must be terminated in its characteristic impedance. An open or short circuit termination would cause total reflection, causing the pattern to become bi-directional.

The unidirectional properties of the antenna originate as follows. An electromagnetic wave traveling from left to right will induce a current on the wire which travels from left to right. This current will be dissipated without reflection in the termination resistor. A small fraction of the current induced by the wave will propagate to the left into the receiver. This fraction causes the backlobes seen in figure 2. Most of the current induced by a wave traveling from right to left propagates to the left into the receiver. This is the main lobe response. A small fraction of this induced current will propagate to the termination resistor where it will be dissipated. The pattern of figure 2 can be reversed (maximum response to the left) by swapping the positions of the receiver and the termination resistor. If a matched receiver were placed at each end of the wire, each would receive independently in opposite directions. This is the basic concept used in the steerable wave antenna to obtain two independent patterns from the same antenna. This concept is also useful in defining the front-to-back ratio of the wave antenna. For a given signal arrival angle the front-to-back ratio (FBR) is:

equ 2.0 $$FBR = \frac{\text{SIGNAL AMPLITUDE IN FORWARD PATTERN}}{\text{SIGNAL AMPLITUDE IN REVERSE PATTERN}}$$

On a single wire wave antenna the FBR can be measured in decibels by reading the change in signal amplitude on a receiver S-meter (calibrated in dB) when the receiver and termination resistor positions are exchanged. On a SWA the FBR is measured by reading the change in dB when the directional switch is thrown. Thus checking the directivity of a SWA is simple as throwing a switch.

2.1 GROUND

Most of the original work on the wave antenna was done at very low frequencies at which the height above ground was of the order of .001 wave. These antennas relied on poor soil conductivity to cause the arriving vertically polarized wave to tilt forward, thereby generating a vector component of the electric field parallel to the wire. The parallel component of the electric field was responsible for inducing a current build-up on the wire as the tilted space wave travelled along the wire. My work with wave antennas in the high frequency bands (1.8 to 7.3 mHz) indicates that wave antennas for these bands should be set up over as nearly lossless ground as possible. Accordingly my wave antennas have parallel ground wires installed along their lengths in order to minimize ground losses. Here are some reasons for low loss grounds.

1. High frequency propagation even at moderate distances is by sky wave. A generous amount of wave tilt is provided by the arrival angle of sky wave signals (typically 20 deg to nearly 90 deg). Therefore, on the average, a large component of the electric field is parallel to the antenna. Lossy soil is not required to produce wave tilt.

2. Lossy ground causes the wave antenna to act as a lossy transmission line. Signal currents induced at the far end can be significantly attenuated on their way to the receiver termination. Contributions to the received signal drop exponentially with distance from the receiving end. When the loss factor is very high only the sections of the antenna nearest the receiving end contribute effectively to the received signal. This results in shortening the effective length of the antenna, decreasing the front-to-back ratio and making the radiation pattern less directional. This will be discussed in greater detail in section 2.7, EFFECTS OF LOSSES. If the losses could be reduced to zero, then all sections of the antenna would contribute equally to its performance, thereby maximizing the effective length.

3. The null-steering performance of long SWA's is destabilized due to the proximity of lossy ground. The reasons are discussed in section 4.4.

4. A lossy ground can cause seasonal and even daily variations in antenna impedance as soil conditions change from dry to rain-soaked to snow and ice covered. The impedance is always changing and the antenna is subject to varying degrees of mismatch. The use of parallel ground conductors or wire

mesh to increase the effective ground conductivity short circuits the variations due to weather and minimizes the effects of ground conductivity anomalies under the antenna. Antenna impedance calculations then become a better predictor of antenna impedance and the design of matching transformers is made independent of soil conditions.

5. Locally generated electrical noise from appliances, arc welders, light dimmers, power line leaks, TV birdies, etc. tends to be vertically polarized. A low loss ground reduces the wave tilt which is necessary to pick up vertically polarized ground wave energy. Reduction of locally generated noise is one of the major reasons given for installing wave antennas.

2.2 ANTENNA PATTERN PLOTS

Two types of computer generated antenna patterns are used in this book, namely elevation and azimuth patterns. The elevation pattern is a planar slice along the axis of the antenna perpendicular to the ground plane. It contains the peak values of the lobe structure. The azimuth patterns are calculated for a specific signal arrival angle above the horizon. An azimuth plot is the intersection between the spatial antenna pattern and the conic surface generated by the angle above the horizon rotated in azimuth. The azimuth plots will not generally contain the peak values of the lobe structure, but are meant to indicate the pattern shape and directivity at an angle above the horizon which represents a typical arrival angle expected in long distance sky wave communications.

The wave antenna responds maximally to vertical polarization along the axial directions, horizontal polarization in the broadside directions and slant ploarization in other directions. In the plots polarization is assumed to be optimally matched to the antenna at each azimuth angle. Thus the plots may be considered to represent the peak response to randomly polarized sky wave signals. Note that these plots will differ substantially from those published for very low frequency (VLF) wave antennas. Since VLF propagation is vertically polarized, VLF plots show antenna response only to vertical polarization. Such plots characteristically have a sharp null which occurs at 90 deg to the antenna axis irrespective of the length of the antenna. The VLF antenna therefore exhibits better directivity than those used in HF service.

All plots (except the linear plot in fig. 2) are done on a logarithmic scale calibrated in decibels. The peak value of each plot is normalized to 0 dB so that pattern shape and directivity can easily be compared.

2.3 ANTENNA LENGTH

The length of the wave antenna has a major effect on pattern shape. The basic elevation and azimuth patterns for wave antennas with lengths of .5, 1, 1.5 and 2 wavelengths are shown in figs. 3 to 6.

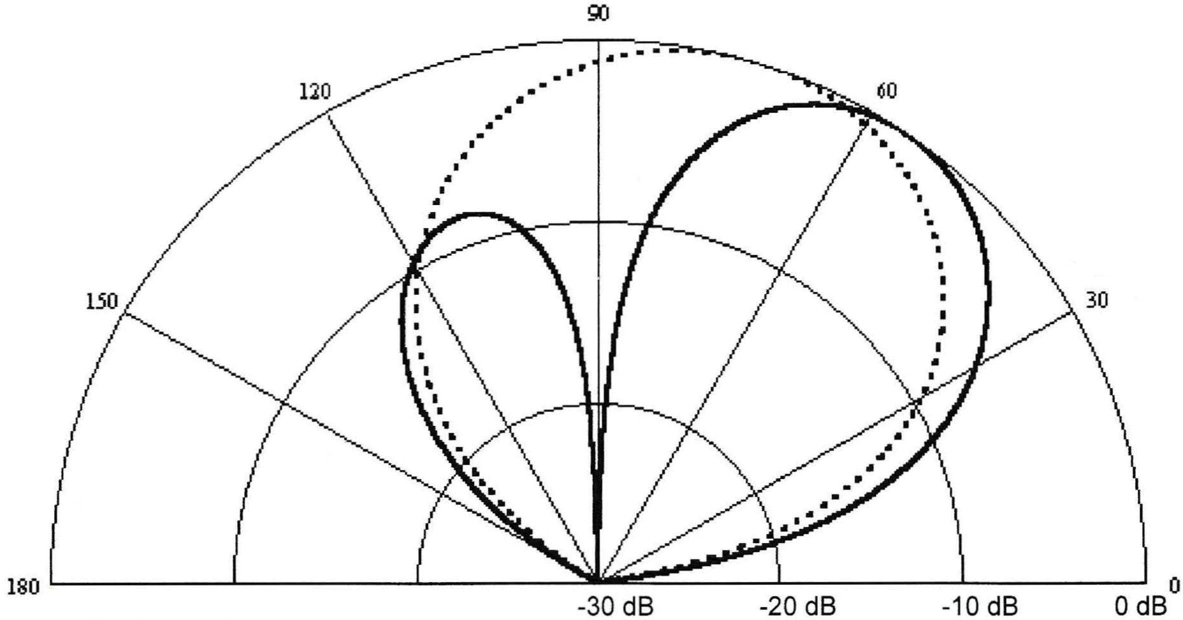


Figure 3. Elevation Patterns

Dotted trace: antenna length = half wave
Solid trace: antenna length = 1.0 wave

Height above ground = .02 wave. Lossless antenna assumed.
Velocity factor = 1.0

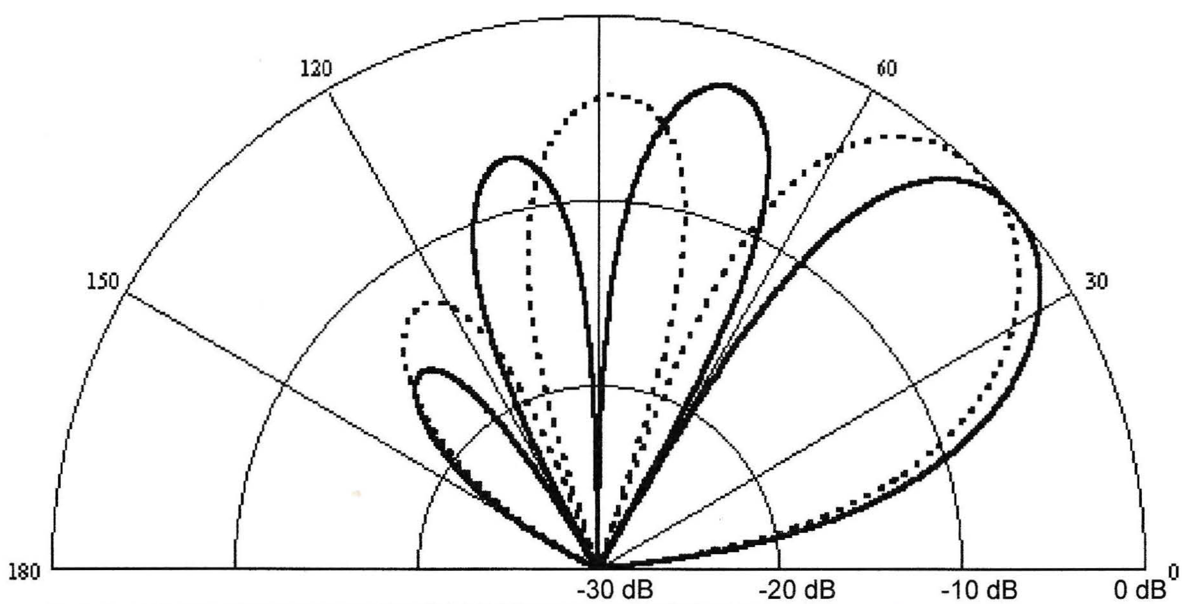


Figure 4. Elevation Patterns

Dotted trace: antenna length = 1.5 wave
Solid trace: antenna length = 2 wave

Height above ground = .02 wave. Lossless antenna assumed.
Velocity factor = 1.0

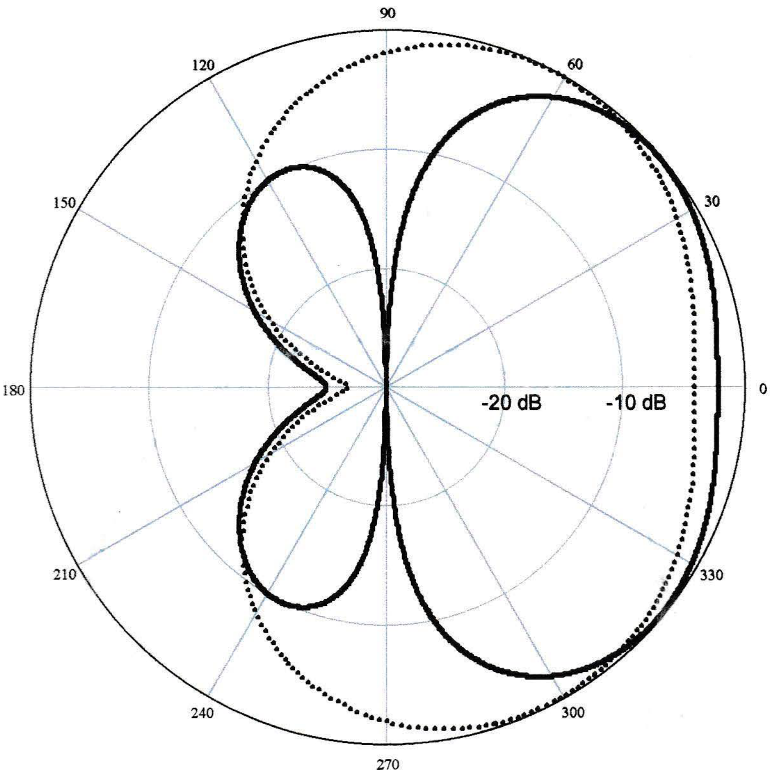


Figure 5. Azimuth Patterns
See fig. 3 for notations.

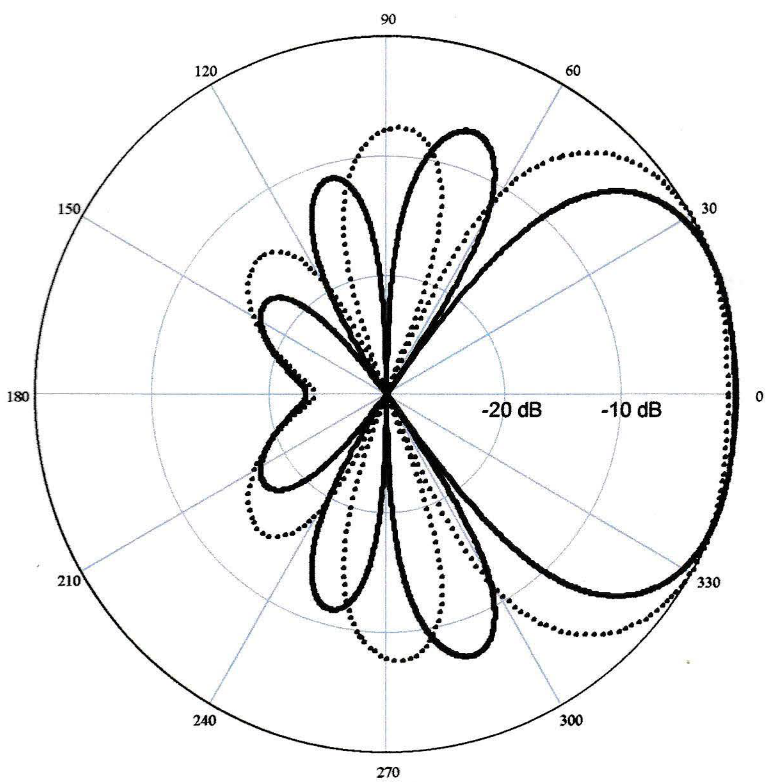


Figure 6. Azimuth Patterns
See fig. 4 for notations.

These plots were calculated at an antenna wave velocity, $v = 1$ where v is expressed as a fraction of the velocity of light. In this case v is equal to the velocity of light in space. The azimuth plots were at a signal arrival angle 30 deg above the horizon.

The following effects can be seen as the length is increased:

1. The main lobe tilts closer to the horizon.
2. The response at low signal arrival angles improves.
3. The number of secondary lobes increases.

Effects 1. and 2. are beneficial to the reception of low arrival angle signals such as might be expected from transmissions originating at great distances. The proliferation of secondary lobes is generally a nuisance which results in the pick-up of noise and interference from unwanted directions and reduces the effective directivity of the antenna. It should be noted that the low angle response will begin to decrease if the length is increased beyond a limit which will be discussed in the following section.

2.4 WAVE VELOCITY EFFECTS

In general the velocity of the electrical signal on the wave antenna is less than the vacuum velocity of light, c. The slowing of wave velocity due to distributed inductance and capacity is well known to users of coaxial cable and open wire transmission line.

H.H. Beverage (QST Magazine, November 1922) measured the velocity of the signal on a wave antenna set up over a soil ground. The velocity is shown to decrease when either antenna height or frequency are decreased.

The wave antenna is also affected by soil conditions. Lossy soil slows wave velocity, an effect which causes the performance of long (e.g., 2 wavelengths) wave antennas to deteriorate.

A low wave velocity places a limit on the practical length of an antenna, beyond which the gain will begin to drop. This limitation is caused by currents in the wire increasingly lagging the wave in space as the length is increased until a point is reached where the current in the wire lags the space wave by more than 90 degrees. Beyond this point the space wave begins to subtract energy from the wave on the wire, causing a drop in signal as the length is increased further. The length at which the 90 degree phase lag occurs is the MAXIMUM EFFECTIVE LENGTH or MEL. MEL is shortened by a decrease in antenna wave velocity or an increase in the arrival angle of the signal with respect to the antenna. MEL can be computed by using the following equation:

equ 2.1
$$MEL = \frac{1}{4(1/v - \cos A)}$$

Where: MEL is maximum effective length in wavelengths.
v is wave velocity as a fraction of the speed of light.
A is the signal arrival angle with respect ot the wire.

The results of calculations using equ 2.1 are shown in Table I for velocities typically encountered in wave antennas. In these examples v = .89, v = .91 and v = .93 can correspond to velocity factors encountered on the 160, 75 and 40 meter bands. The practical use of Table I is simplified by assuming that the antenna will be used for DX reception in which case a signal arrival angle of 20 degrees would be a reasonable choice around which to center antenna designs.

TABLE I

Signal Arrival Angle (A) degrees	Maximum Effective Length (MEL) in Wavelengths		
	v = .89	v = .91	v = .93
0	2.02	2.53	3.32
10	1.80	2.19	2.76
20	1.36	1.57	1.84
30	.97	1.07	1.19
40	.70	.75	.81
50	.52	.55	.58

Wave velocity may be increased slightly by:

1. Using a thin single wire antenna.
2. Increasing the height above ground.
3. Installing parallel ground wires under the antenna.

A slower wave velocity decreases the main lobe response of wave antennas of any length. However, when space restrictions limit the length to under .5 wave, the front-to-back ratio (FBR) can be substantially improved by reducing the wave velocity. An example of this is shown in figure 7. The azimuth pattern of a .4 wave antenna is plotted with velocity factors v = .9 and v = .58 A velocity factor of .9 was chosen to represent a typical practical antenna. The .58 factor was realized by using a zig-zag wire configuration. The improvement in FBR is apparent in the plot, but at the cost of slightly less (2 dB) signal pick-up.

Wave velocity may be reduced by:

1. Use of thick wire.
2. Parallel wide spaced multiple wires.
3. Reduced height above ground. Not recommended...increases attenuation.
4. Use of slow-wave configurations such as zig-zag wire, periodic series inductive loading, periodic capacitive loading or others yet uninvented.

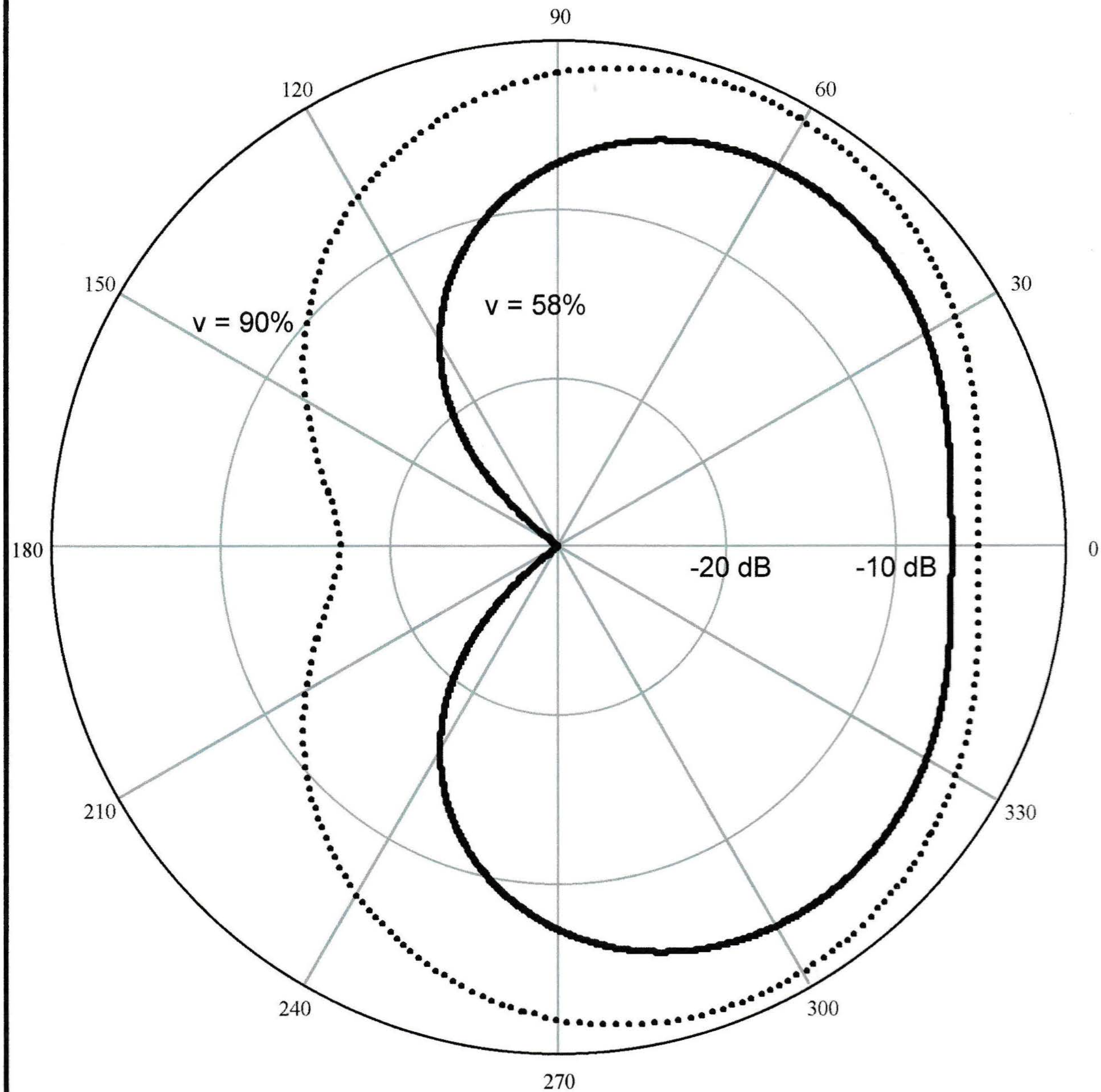


Figure 7. Effect of slowing the wave velocity.

Dotted trace: antenna with velocity at 90% of speed of light.
(90% is typical of actual wave antennas)
Solid trace: antenna with velocity at 58% of speed of light.
A zig-zag wire configuration was necessary to get to 58%.

Antenna length = .4 wave   Height = .02 wave
Signal arrival angle = 30 deg above horizon.

The 58% velocity pattern in figure 7 very closely approximates the directivity of a full half wave antenna. A slow wave antenna when combined with null steering provides a very powerful method for improving the performance of short wave antennas. The MICROSLO discussed in section 4.6, chapter 4 combines the low wave velocity with null steering to provide an ultra-short SWA with improved performance. Chapter 5 discusses the construction of the MICROSLO.

More information about wave velocity is found in sections 2.5 and 2.9

2.5 WAVE VELOCITY MEASUREMENTS

A knowledge of wave velocity is required in the selection of optimum and maximum effective lengths of wave antennas. The velocity may be measured after the antenna is set up. The technique for single wire and multi-wire arrangements is essentially the same. The multi-wire is treated as a single wire by electrically connecting the wires together at the ends. In center-fed SWA's the center termination should be by-passed during measurement.

A diagram of the test set-up is shown in figure 8. The antenna under test is open-circuited at both ends (i.e., not grounded) and points X and Y on the r--f voltmeter are connected to points X and Y respectively on the input side of the antenna. Here the combination of a d-c micro-ammeter, diode and capacitor form the r-f voltmeter. The signal generator should have an output which remains constant as frequency is varied. The 0-50 micro-amp meter will show maximum readings at frequencies at which the antenna length is a multiple of an electrical half wave. An electrical half wave is defined as the free space wavelength times the velocity factor. The lowest frequency at which a voltage peak will be found is the frequency at which the antenna length is one electrical half wave. The frequencies at which voltage peaks will be found will be 1, 2, 3, etc. electrical half waves. You will have to tune the frequency dial back and forth to accurately determine the location of the peak. The signal generator output should be adjusted to give a nearly full scale reading on the r-f voltmeter in order to maximize the accuracy with which the maxima frequencies can be found. On a real antenna the velocity increases slightly at higher frequencies so that the multiple half wave frequencies are only approximate multiples of the half wave frequency. The 1, 2, 3, etc. electrical half wave frequencies should be recorded so that wave velocity can be calculated. The physical length of the antenna must be measured, recorded and converted into meters (1 foot = .3048 meters). The wave velocity calculation finds the ratio between the velocity on the antenna and the velocity in free space as follows:

equ 2.2
$$v = \frac{L\,f}{150\,N}$$

Where:
v is velocity as a fraction of free space velocity.
L is physical length in meters.
(definitions continued on next page)

ANTENNA TEST SET-UP

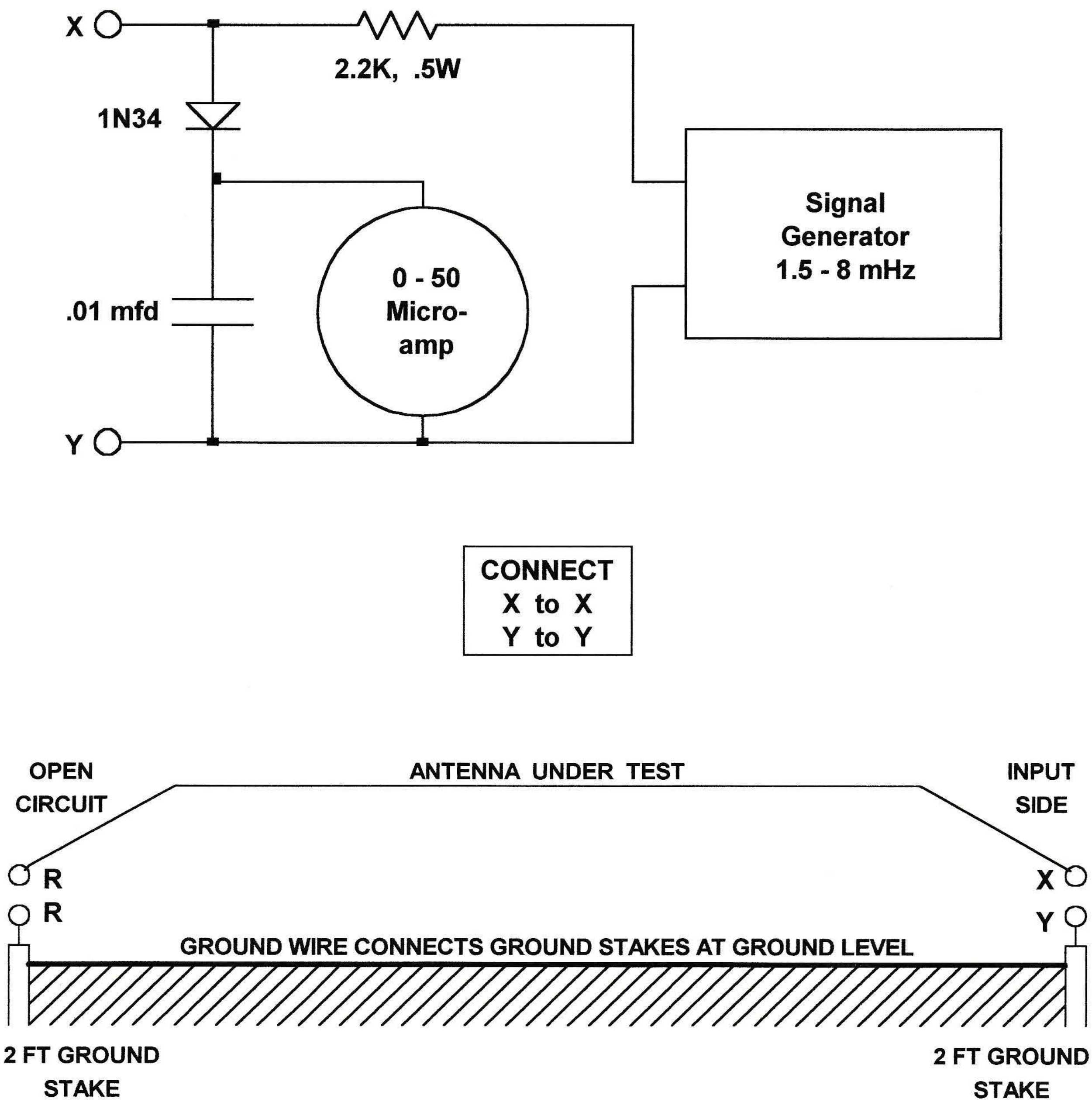


FIGURE 8

f is frequency in mHz.
N is the number of half waves at frequency f.

The above procedure results in a series of velocities corresponding to a series of discrete frequencies. To obtain velocities at frequencies other than those representing half wave multiples there are two techniques which are useful. The simpler of the two is to plot the data points as velocity versus frequency and then drawing a smooth curve through the data points. Intermediate velocities may then be read off the curve.

Another method utilizes regression analysis to fit the data to a power law expression of the form:

equ 2.3 $$v = b f^{m}$$

Where: v is velocity
f is frequency
b and m are constants determined by the analysis

This equation mimics the velocity vs frequency data over a wide frequency range. The regression analysis computes the values of b and m which produce the best fit to the data. The analysis also yields a measure of the accuracy of the fit, namely the correlation coefficient, r.

A typical wave antenna yielded the following equation:

equ 2.4 $$v = .65891 f^{.038523821}$$

Where the frequency is in kHz.

The equation is valid over a frequency range of roughly 1.6 to 10.5 mHz.

2.6 END TERMINATION

The single wire wave antenna must be terminated in a non-inductive resistance equal to the characteristic (surge) impedance of the wire in proximity with the ground. In this respect the antenna is like a transmission line operating into a matched load. Signals propagating toward the end termination are absorbed completely resulting in an input impedance which is nearly constant over a wide frequency range, e.g. d-c to 10 mHz.

The test set-up shown in figure 8 may be used to determine the termination resistance required. It should be noted that the ends of the antenna slope gradually to the ground. This is done to avoid vertical downleads at the ends. Unshielded vertical downleads cause omnidirectional pick-up which pollutes the directivity of the antenna. Vertical downleads also cause an abrupt transition which sets up spurious reflections. A sloping termination which makes an angle with the ground of approximately 10 degrees minimizes (but does not entirely avoid these problems). The characteristic impedance, Zo, of a single wire antenna over a perfect ground may be calculated to provide a starting value for

selecting a termination resistor using the following equation.

equ 2.5 $$Zo = 138 \log_{10}(4h / d)$$

Where: d is wire diameter.
h is height above ground ($h > d$)

Diameter and height must be expressed in the same units. The diameter of the wire can be calculated from the AWG wire gauge using the following formula:

equ 2.6 $$d(\text{inches}) = \frac{.46}{92^{(AWG + 3)/39}}$$

This formula, evaluated on a scientific hand calculator or computer, eliminates wire tables.

Table II has been calculated using the above equations for typical antenna heights and wire size combinations. It may be noted that Zo does not change very rapidly with either height or wire size. Neither table II nor the calculated values of Zo take into account the effects of the sloping sections, hence the values shown should be looked upon as experimental starting values.

I recommend Allen-Bradley .5 watt composition resistors and Ohmite composition potentiometers as termination resistors in the d-c to 10 mHz range. A 100 ohm resistor in series with a 500 ohm pot connected as a variable resistor will match a very wide range of antennas. An ohm meter may be used to set the resistance to the approximate value of Zo. Connect the variable termination between the points R-R in figure 8. The input side of the antenna is fed with a signal generator through a 2.2K series resistor as shown in the upper portion of figure 8.

TABLE II

Height above ground (feet)	CHARACTERISTIC IMPEDANCE, Zo, Ohms		
	#16 AWG wire	#14 AWG wire	#12 AWG wire
6	518	504	490
8	535	521	507
10	549	535	521
15	573	559	545
20	590	576	562

Points X and Y on the r-f voltmeter are connected to points X and Y respectively on the input side of the antenna. Assuming the antenna will be used on the

amateur bands, 1.8 through 7.3 mHz, the signal generator should be capable of covering this range with constant voltage output. The procedure for optimizing the termination is as follows:

1. Start at the low end of the frequency range. Adjust the signal generator to give half scale reading on meter.
2. Slowly tune through the frequency range. Find the frequency at which the meter reading is maximum. At this frequency re-adjust the signal generator output to give a full scale reading.
3. Slowly tune through the frequency range and record the minimum reading.
4. Record the termination resistance value and the corresponding max (full scale) minus min reading in your notebook. The objective of this procedure is to minimize the difference between max and min readings.
5. Make a small change in the termination resistance. Measure its new value with the ohm meter and record it in your notebook. Repeat steps 2, 3 and 4 and record the new max minus min. If max minus min increased, then you incremented the resistance in the wrong direction. If max minus min decreased, then continue to increment R in the same direction. Always repeat steps 2, 3 and 4 after each increment. The procedure can stop when you can no longer reduce the max minus min readings. The variable termination can then be replaced with .5 watt fixed composition resistors.

Because of sloping end sections, coupling with nearby antennas or height variations over bumpy ground there will generally be some residual value below which it is not possible to reduce the max minus min value. Typically expect a minimum reading roughly 90% of maximum.

It should be noted that the termination resistance found by the above procedure is not the true characteristic impedance of the antenna because the ground stake is not a perfect ground and is likely to add extra ohms of termination resistance. Not to worry. The matching procedure compensates for it by including it with the termination resistor during measurement.

The presence of nearby resonant antennas can disturb the impedance measurements and performance of the wave antenna. Some typical offenders are quarter wave verticals grounded at the base and half wave dipoles running parallel to the wave antenna. Mutual coupling can be reduced by open-circuiting the base of quarter wave verticals, grounding the base of half wave verticals, running dipoles at right angles to wave antennas and maximizing spatial separation.

2.7 EFFECTS OF LOSSES

The primary sources of attenuation along the wave antenna are the interaction of the electromagnetic field with the nearby lossy ground and ohmic losses in the wire itself. Of these the field interaction predominates as the most important loss mechanism. Because the losses are evenly distributed along

the wire, signals attenuate exponentially as they propagate down the wire. Said another way, each unit of length produces a constant percentage loss of signal. The loss as a function distance is given by:

equ 2.7 $$A = e^{-aL}$$

Where: A is the loss factor which is simply the fraction of the signal voltage remaining after traveling L units along the wire.
a is the loss coefficient.

When L equals the length of the antenna A becomes the end-to-end loss factor which can be easily measured (see next section). This is the loss factor shown in my antenna pattern plots. The effect of various loss factors on antenna performance can be assessed in figure 9 in which a lossless antenna (loss factor = 1) is compared with antennas having loss factors of .5 and .25 (the smaller the loss factor the greater the loss). As the loss increases, the response to signals decreases everywhere except in the null regions. Of particular importance for DX-ers is the loss-induced decline in the response in the low arrival angle regions of the main lobe.

Less obvious in figure 9 is the degradation of front-to-back ratio as losses increase. The effects of losses may be summarized:

1. Decrease in signal response everywhere except in null regions.
2. The nulls become filled in and less distinct.
3. The front-to-back ratio (hence directivity) is reduced.

The end-to-end loss may be reduced by increasing the height of the antenna or by increasing the conductivity of the ground. Ground conductivity can be increased by installing parallel ground wires under the antenna. These should be symmetrically placed if there is more than one. They should run the full length of the antenna and can be terminated on ground stakes. Insulated wire is preferable and wire size is not critical, but one should favor thick conductors if available at low cost.

Ground wires running in random directions under the antenna are likely sources of loss of directivity. This remark also applies to metallic fences, water pipes or other sources of asymmetry.

2.8 END-TO-END LOSS MEASUREMENT

The end-to-end loss may be measured by using the following procedure:

1. Terminate the wave antenna in its characteristic impedance

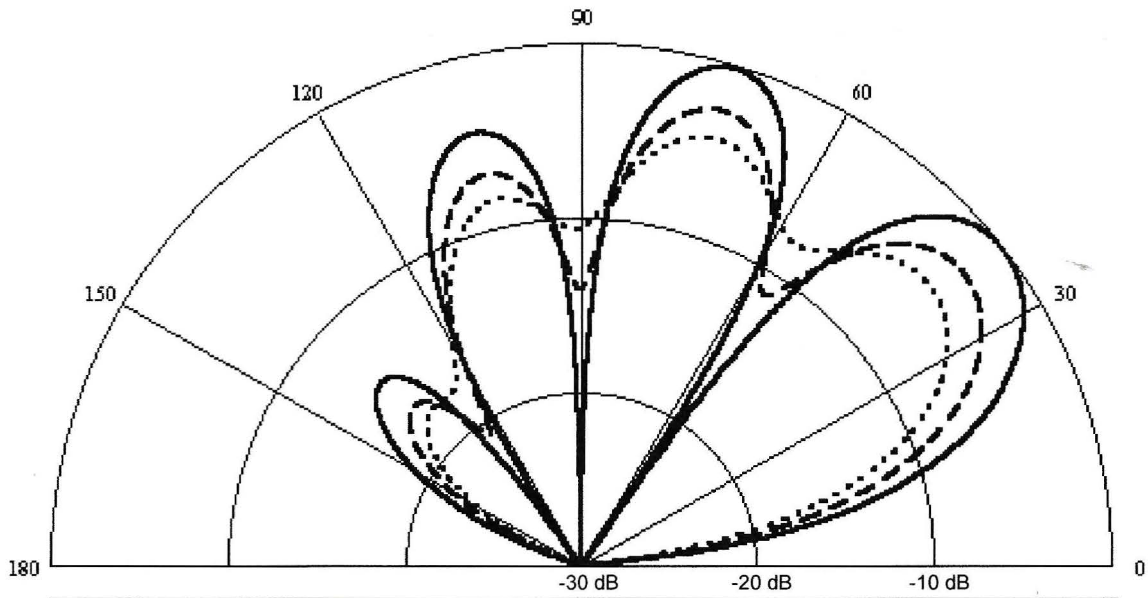


Figure 9. The Effects of Loss

Solid trace: loss factor = 1
Dashed trace: loss factor = .5
Dotted trace: loss factor = .25

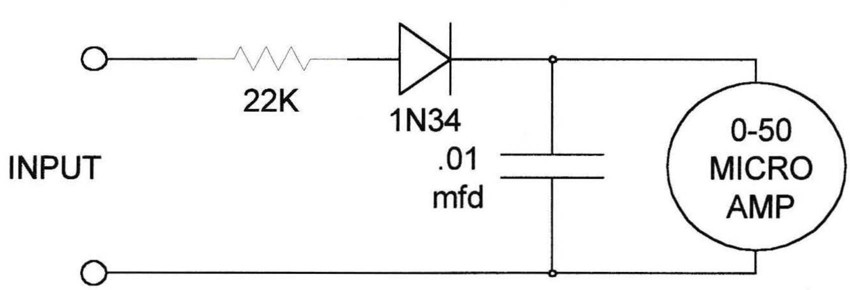
Height above ground = .02 wave   Length = 1.8 wave
Velocity factor = .9

(as described in section 2.6).

2. Set signal generator to desired frequency, then input a 1.0 volt signal across X-Y in figure 8.
3. Using a high impedance r-f voltmeter measure the voltage across the termination resistor. The loss factor is equal to this voltage.

On a properly terminated antenna the termination voltage will always be less than the input voltage. The loss factor is then simply the termination voltage divided by the input voltage.

If a high impedance r-f voltmeter is not available the r-f voltmeter shown in figure 8 can be modified for end-to-end loss measurements. The modifications shown in the following diagram increase the impedance and improve the linearity.



After the foregoing modifications are made the readings may be linearized by using the following transformation:

equ 2.8
$$V = .088778662\,R^{.9044683909}$$

Where: V is the voltage
R is the reading on the 0-50 micro-amp meter.

Full scale reading is 3.05 volts. Equ 2.8 is designed specifically to linearize the 1N34 germanium diode. If a high impedance r-f voltmeter is available, of course, all of this folderol will be avoided.

2.9 FRONT-TO-BACK RATIO (FBR)

The FBR is a measure of antenna directivity. It is defined as the ratio of antenna response in the forward direction to the response in the reverse direction at a given arrival angle.

The FBR may be clearly defined for a special class of wave antennas. This is the class of antennas whose length is either an electrical half wave or any multiple thereof. The FBR of this class of antennas is given by:

equ 2.9
$$FBR = \left[\frac{(aL/\pi)^2 + (1 + v\cos(\theta)^2}{(aL/\pi)^2 + (1 - v\cos(\theta)^2}\right]^{1/2}$$

Where: a is the loss coefficient as defined in equ 2.7
L is the length of an electrical half wave.
v is wave velocity on the antenna
θ is the signal arrival angle.
π = 3.141592654 (approximately)

From equ 2.9 it can be seen that FBR does not change when electrical half wave increments are added to the antenna. The factor representing the number of electrical half waves dropped out in the transformations which yielded equ 2.9. This conclusion is made more interesting by the fact that adding half wave increments drastically changes the shape of the antenna pattern.

FBR's calculated for an arrival angle of 10 degrees have been tabulated in table III for various combinations of velocity and loss factor. The range of values include those encountered in practical h-f wave antennas. The loss factors range from lossless (ideal) to very lossy. The loss factors shown are per electrical half wave. The following conclusions may be drawn from equ 2.9:

1. FBR is maximum at zero wave arrival angle.
2. FBR is 0 dB (1:1) at a 90 degree arrival angle.
3. FBR is decreased by increasing loss.
4. FBR is decreased by decreasing the velocity.

This discussion has been restricted to a single class of wave antennas with length restricted to electrical half wave multiples. A more generalized view of FBR is presented in section 2.95 with a method of optimizing FBR over a range of arrival angles.

It is difficult to visualize equ 2.9, so I have "nested" the patterns of .5, 1 and 2 wavelength wave antennas in figure 10 below. The amplitudes were adjusted so that the patterns are tangential at low angles. You can easily check out the equality of FBR at any arrival angle despite the large differences in pattern shape.

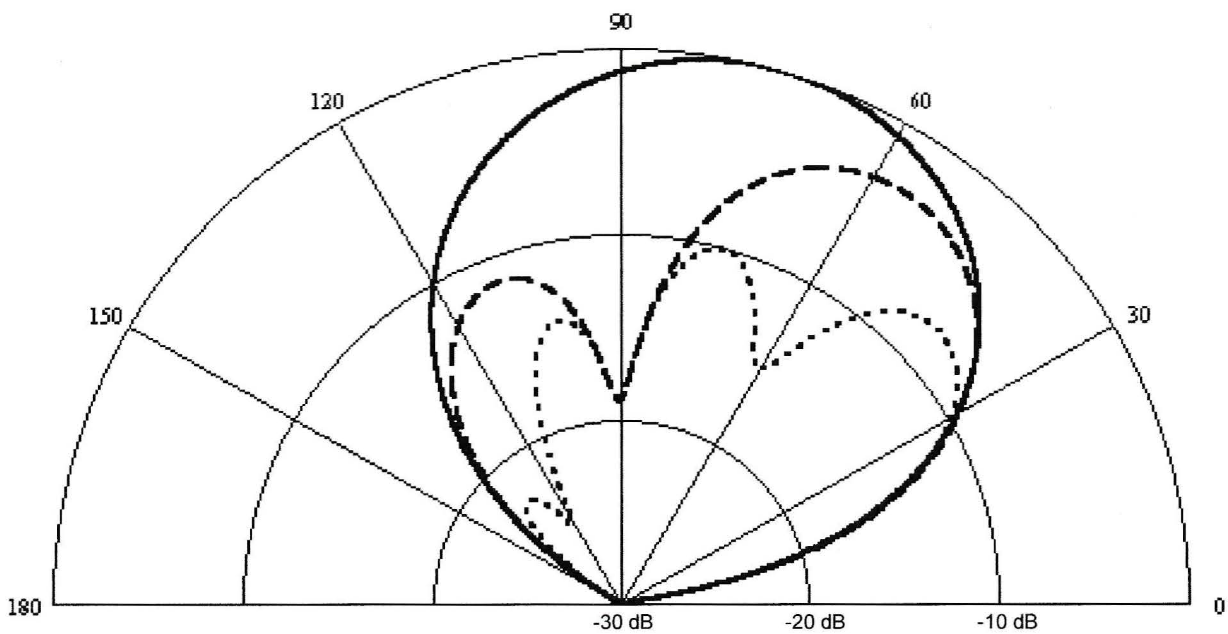


Figure 10. Nested Antenna Patterns
Solid trace: .5 wave antenna
Dashed trace: 1 wave antenna
Dotted trace: 2 wave antenna
Attenuation coefficient, a = .5 Height = .02 wave
Velocity factor, v = 1

Remember that FBR depends on pattern shape and has little to do with the ability of the antenna to pick up low angle signals. If the 2 wave pattern were presented at full amplitude, its low angle performance would greatly exceed that of the .5 wave pattern.

TABLE III

FRONT-TO-BACK RATIO IN DB AT 10 DEG ARRIVAL ANGLE Length = Any integral number of electrical half waves.					
Velocity Factor, v	LOSS FACTOR PER ELECTRICAL HALF WAVE LOSSLESS - VERY LOSSY				
	A = 1	A = .8	A = .6	A = .4	A = .2
1.0	42.3	28.7	21.7	16.7	12.0
.95	29.6	26.1	20.9	16.3	11.8
.94	28.3	25.5	20.7	16.2	11.7
.93	27.2	24.8	20.4	16.1	11.6
.92	26.1	24.2	20.2	16.0	11.6
.91	25.2	23.6	19.9	15.8	11.5
.90	24.4	23.0	19.6	15.7	11.4
.89	23.6	22.4	19.3	15.6	11.3
.88	22.9	21.8	19.0	15.4	11.3
.87	22.3	21.3	18.7	15.2	11.2

2.91 HEIGHT ABOVE GROUND

Height above ground has little effect on directivity at heights less than an eighth wave. Lower antenna height generally increases end-to-end loss and lowers wave velocity. These secondary effects rather than height itself have the greatest effect on directivity

2.95 CONE OF SILENCE MODE

Is there an optimum length for a wave antenna? The ideal or optimum wave antenna would have the following characteristics:

1. Maximum response in the forward direction, particularly to low arrival angle signals.
2. Zero response in the reverse direction.

Unfortunately an optimization which includes the entire forward and reverse hemispheres is not practical. However an optimization which compares the forward 90 degree apex angle cone to the reverse 90 degree cone is quite practical. The sides of these cones make a 45 degree angle with the wire. The approach I have used is to maximize the conic front-to-back ratio, CFBR, defined as the ratio of maximum response in the forward cone to the maximum response in the reverse cone.

The optimization yields optimum lengths at which CFBR is maximized. The optimum lengths are affected by wave velocity and loss factor.

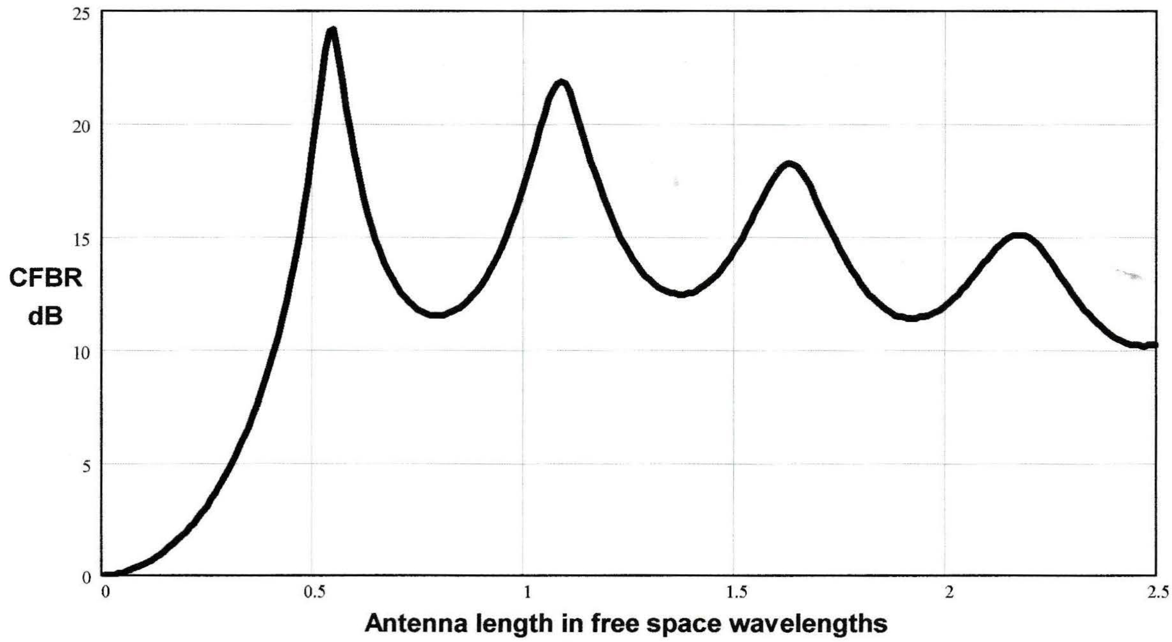


Figure 11. Conic Front-to-Back Ratio (CFBR) vs Antenna Length
Attenuation coefficient, a = .6485 Velocity factor, v = .89
Height above ground, H = .02 wave

Since the maximum response in the reverse cone is minimized by this process, an antenna cut for this condition is said to be in the CONE OF SILENCE (COS) mode.

In figure 11 I have plotted CFBR versus antenna length. The antenna parameters were chosen to simulate a practical antenna. As can be seen, the CFBR exhibits periodic sharp peaks as the length is increased. Peaks occur at multiples of the shortest cone-of-silence (COS) length. At the shortest COS length the CFBR is at least 20 dB over an 11% bandwidth, enough to cover the 1.8 to 2.0 mHz band.

For working DX the COS length should be the maximum which will not seriously violate the maximum effective length derived from table I. In practice this turns out to be the third peak, roughly 1.64 wavelengths on the 1.8 mHz band, but 2.18 wavelengths on the 3.9 and 7.0 mHz bands. Longer lengths (as expressed in wavelengths) are feasible at the higher frequencies because antenna wave velocity is higher at higher frequencies, but note that a 2.18 wave 7.0 mHz antenna is physically much shorter than a 1.64 wave 1.8 mHz antenna.

For attenuating broadcast stations, man made interference and natural static, the maximum CFBR is required, calling for the shortest COS length. The shortest COS length also results in the stablest nulls when null-steering is used on sky-wave signals. This is discussed in chapter 4.

The following procedure may be used for determining the length of a COS mode antenna:

TABLE IV
CONE OF SILENCE MODE DATA

VELOCITY	LOSS FACTOR	MINIMUM COS LENGTH WAVES	CFBR dB
.95	1.0	.554	30.4
.95	0.8	.562	27.7
.95	0.6	.568	21.3
.94	1.0	.550	30.4
.94	0.8	.558	27.7
.94	0.6	.564	21.3
.93	1.0	.546	30.5
.93	0.8	.554	27.7
.93	0.6	.560	21.2
.92	1.0	.542	30.5
.92	0.8	.550	27.7
.92	0.6	.556	21.2
.91	1.0	.540	30.5
.91	0.8	.548	27.7
.91	0.6	.554	21.2
.90	1.0	.536	30.5
.90	0.8	.544	27.7
.90	0.6	.550	21.1
.89	1.0	.532	30.6
.89	0.8	.540	27.6
.89	0.6	.546	21.1
.88	1.0	.528	30.6
.88	0.8	.536	27.6
.88	0.6	.542	21.1
.87	1.0	.526	30.6
.87	0.8	.532	27.6
.87	0.6	.538	21.0
.86	1.0	.522	30.6
.86	0.8	.528	27.6
.86	0.6	.534	21.0
.85	1.0	.518	30.6
.85	0.8	.524	27.6
.85	0.6	.530	21.0
.84	1.0	.514	30.7
.84	0.8	.520	27.6
.84	0.6	.526	20.9

1. Set up the antenna cut to .54 wavelengths (freespace).
2. Measure the wave velocity (section 2.5).
3. Measure the loss factor (section 2.8).
4. Look up the minimum COS length in table IV using the measured loss factor and velocity. Because the differences are small you can interpolate linearly between values of loss factor.
5. The minimum length can then be multiplied by 2, 3 or 4 in order to operate at one of the peaks shown in figure 11.

I have plotted the elevation pattern of a COS mode antenna in figure 12 (solid trace). The length is three times minimum COS length (third peak from the left in figure 11). This was determined by using v = .89 and loss factor (per .54 wave) = .8 to find the COS length of .540 wave in table IV. This length was multiplied by three to yield 1.62 wavelengths (free space). The COS region is 135 to 180 degrees.

A comparison plot is shown for an antenna with the same velocity and loss factor, but with a length of 2 wavelengths (dotted trace). Because the 2 wave antenna violates MEL in table I, it has less gain in the forward direction and a poorer CFBR than the COS design. MEL at 14 degrees is 1.62 wavelengths, thus the COS design can be expected to perform well on low angle DX signals.

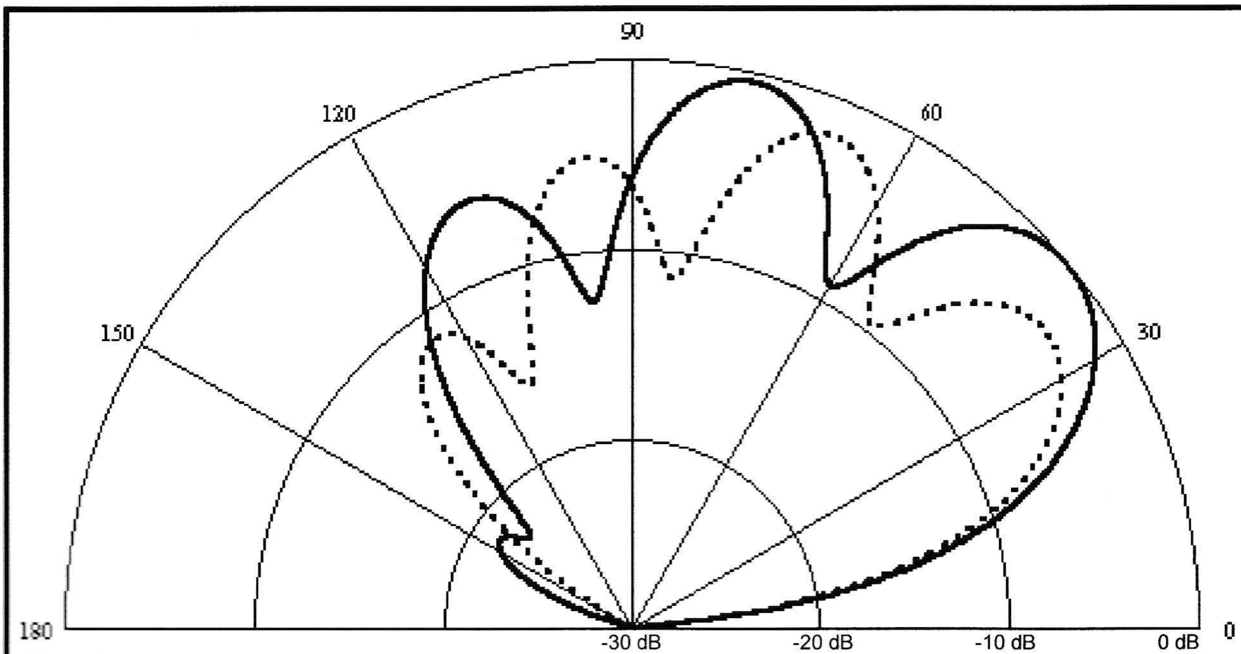


Figure 12. COS Elevation Pattern

This is a comparison between a COS antenna (solid trace) and a 2 wavelength antenna (dotted trace) which exceeds the MEL criterion.

Lengths: COS antenna = 1.62 wave (solid trace), 2 wave antenna dotted trace

v = .89 Attenuation factor = .8 per .54 wave H = .02 wave

3 SINGLE WIRE WAVE ANTENNA CONSTRUCTION

3.1 THE DOUBLE SLOPER

The diagram of the double sloper is shown in figure 13. As the name implies, a sloping termination is used at each end. The sloping terminations avoid the use of vertical downleads which pollute the directivity by adding non-directional input.

At a flat-top height of 10 feet the slope of the end sections is just under 10 degrees. If the height is less than 10 feet the length of the sloping sections can be reduced proportionally, i.e., at a 7 foot height the sloping sections would be 42 feet in length.

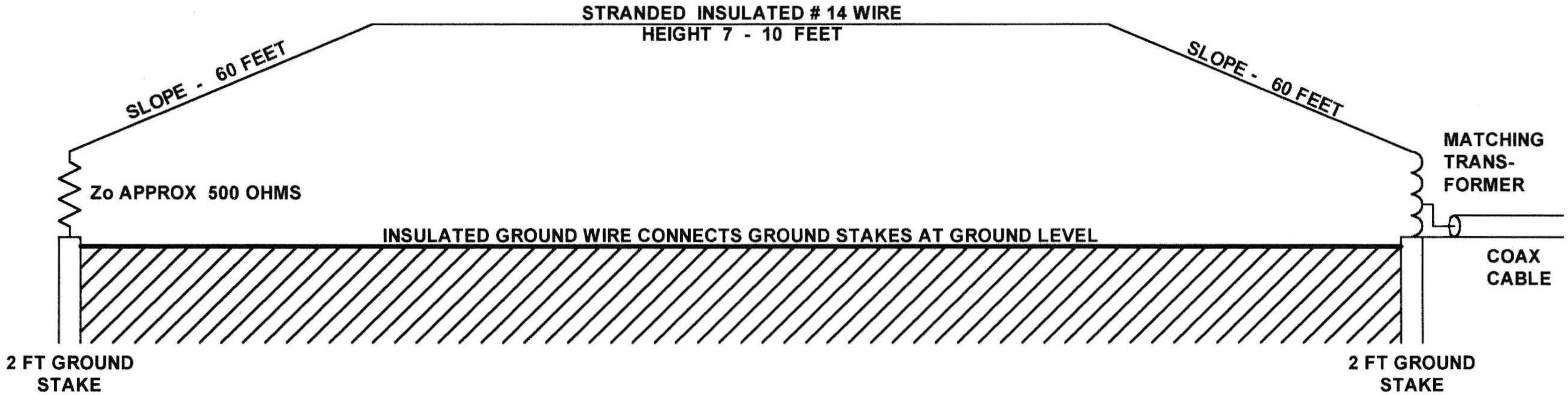
Both ends of the antenna are terminated on ground stakes whose length is not critical. For ordinary soil a 2 foot ground penetration is sufficient. If you live on dry poorly conducting sand it might be better to bury a large metal object like an old water tank. An automobile hood flattened and laid flat on or slightly below the surface of the ground is a better ground than a ground stake. An insulated wire connects the ground stakes at ground level. The size of the wire is not critical, but thicker wire is better. Read section 5.51 for more ground system details.

The termination resistance, Zo, should be selected by using the procedure outlined in section 2.6. However, a 500 ohm .5 watt composition resistor is a reasonable starting point. Avoid wire wound resistors entirely, as they are not purely resistive at radio frequencies. Because Zo varies very slowly with height or wire size 500 ohms would be a reasonable quick-fix to get the antenna up in time for a contest.

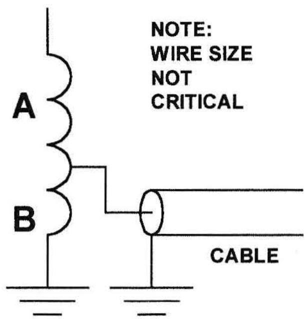
The matching transformer shown in figure 13 is an auto-transformer wound on a Ceramic Magnetics MN8CX core. The last page of this book contains information on ordering cores. This information is subject to change so it is important to confirm prices, etc. by mail or e-mail. The antenna impedance is roughly 521 ohms. Therefore the transformer is designed to look like 521 ohms to the antenna when a receiver impedance of 50 ohms is connected. Because of the core shunt resistance and reactance per turn squared, the impedance looking from the receiver will be less than the rated value, e.g., 42 ohms typical rather than 50.

The length of the antenna has not been specified in figure 13. Because of its matched termination antenna impedance is the same for any length you choose. I recommend using the cone-of-silence lengths described in section 2.95. If the antenna must be assembled without benefit of measurements I recommend a multiple of .55 wave. If other lengths are selected, the effect on CFBR can be estimated from figure 11. Read section 5.1 before beginning construction.

THE DOUBLE SLOPER



30 KEVLAR COATED WIRE WOUND CLOSE SPACED ON MN8CX CORE(S). SEE FINAL PAGE OF BOOK FOR RECOMMENDATIONS AND PRICES.
WE ALSO SUPPLY BRONZE FUSE CLIPS FOR MOUNTING CORE(S)/ TRANSFORMERS.



NOTE:
WIRE SIZE NOT CRITICAL

TRANSFORMER DETAILS

TRANSFORMER TURNS		
	50 OHM COAX	75 OHM COAX
A	12 Turns	10 Turns
B	5 Turns	6 Turns

Figure 13.

3.2 ALTERNATE RECEIVER TERMINATION

There are installations where a sloping termination cannot be tolerated because people or vehicles must pass under the antenna. An alternate receiver termination is shown in figure 14. Downlead pick-up is balanced out using a bucking transformer. In effect a mismatch due to capacitive loading is the price paid for downlead shielding. The mismatch does not affect antenna directivity because the reflected energy is dissipated in the termination resistor. The downlead wires are thin and wide-spaced to minimize capacitive loading.

3.3 FREQUENCY RANGE

Experimental research has yielded significant improvements in the efficiency of r-f transformers used in Beverage antenna construction. The MN-60 and BBR-7731 core materials have been replaced by higher efficiency MN8CX material. The insertion loss of r-f transformers using the MN8CX material is shown below in table V over a frequency range of 100 kHz to 10 mHz. It is clear from the table that additional efficiency may be obtained by stacking two cores in each transformer. The procedure is simple. Just place one core on top of another and wind the transformer using the turns information in the antenna diagrams. At 10 mHz a single core is more efficient. Double coring improves performance at all other listed frequencies. For use in the 160-190 kHz experimental VLF band I recommend using 3 cores per transformer. Cores can be held together by epoxy to make handling easier when winding.

TABLE V

TRANSFORMER INSERTION LOSS dB		
MHz	Single MN8CX core	Double MN8CX core
0.1	- 8.01 dB	- 3.70 dB
0.5	- 1.03	- 0.38
1.0	- 0.57	- 0.24
1.8	- 0.51	- 0.21
2.0	- 0.49	- 0.18
3.5	- 0.32	- 0.07
3.9	- 0.27	- 0.03
7.2	- 0.40	- 0.32
10.0	- 1.29	- 1.42

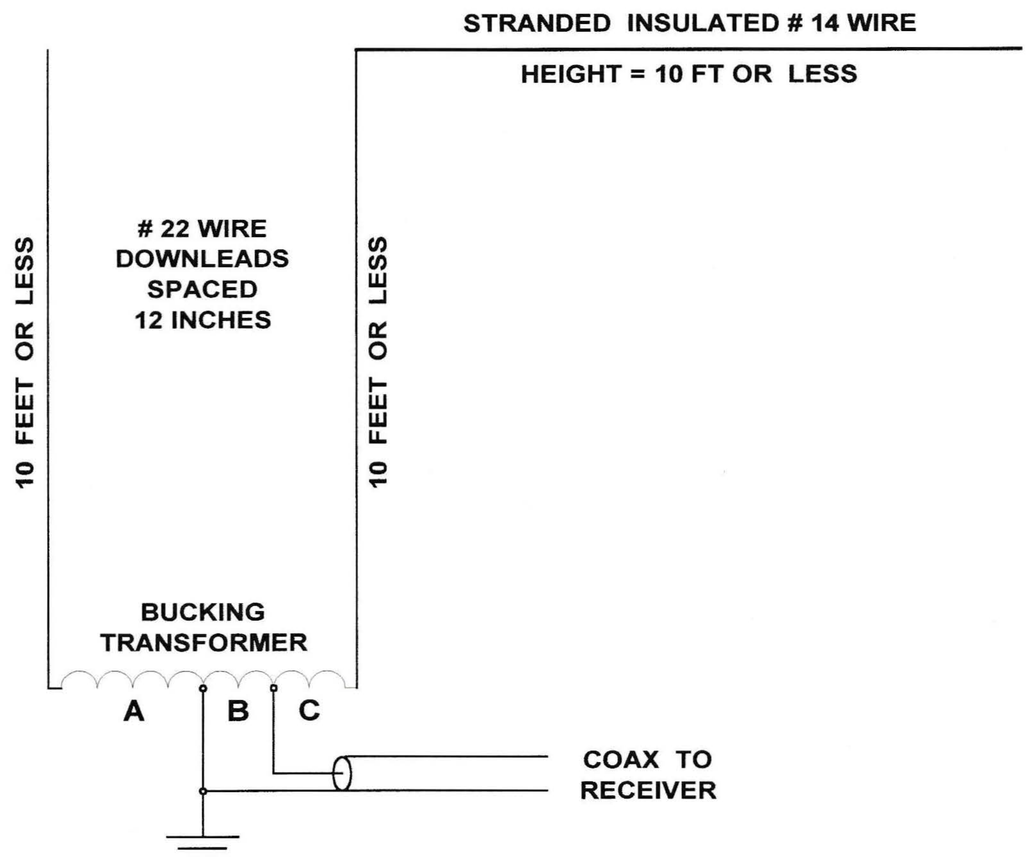
Above results apply only to cores dimensioned: O.D. = 0.5 in., I.D. = 0.312 in., T = 0.25 in.

RECOMMENDATION FOR ALL SWA TRANSFORMERS

Use # 30 kevlar coated wire. RADIO SHACK catalog numbers 278-501 (red), 278-502 (blue), strip tool 276-1570.

FIGURE 14.

ALTERNATE RECEIVER TERMINATION



TRANSFORMER WOUND WITH # 30 KEVLAR COATED WIRE ON MN8CX CORE MOUNTED IN BRONZE FUSE CLIP.
CHECK SECTION 3.3 FOR DETAILS.
FOR CORE AND FUSE CLIP PRICES CHECK LAST PAGE IN BACK OF BOOK.

TURNS REQUIRED		
	50 OHM COAX	75 OHM COAX
A	17	16
B	5	6
C	12	10

4 STEERABLE WAVE ANTENNA THEORY

A diagram of the SWA is shown in figure 15. The two wires in the antenna are parallel, side-by-side and at the same height, H, above ground. The two wires act as a single antenna. A passing radio wave induces equal in-phase (push-push) currents on both wires.

The SWA is unusual because it possesses two independent simultaneously accessible directivity patterns. A typical pair of mirror image directivity patterns is shown in figure 15. To simplify the discussion the rightward pattern will be called pattern A and the leftward pattern pattern B. The output of coax A is pattern A and the output of coax B pattern B. The pattern shape is the same as the pattern shape for a single wire antenna with the same parameters (length, wave velocity, attenuation coefficient and height). Unlike the single wire wave antenna, both patterns are available at the same end of the antenna. Thus the SWA is basically a wave antenna whose terminations have been transposed to the receiving end. This arrangement provides great flexibility in controlling the antenna with simple switching and phasing circuits.

Let us examine how the two patterns are formed. First assume a signal arriving from the right within lobe 1 of pattern A. This signal will induce equal in-phase currents on the wires, causing an electric wave to propagate toward the left. The antenna currents, being in phase, will drive transformer B in push-push, resulting in cancellation of signal in transformer B. Moreover the impedance of transformer B will be zero when driven in push-push, thereby transferring all of the signal to transformer A. The main lobe pick-up of pattern A therefore appears at the output of coax A.

A signal arriving from the left aligned with lobe 1 of pattern B induces equal in-phase currents which propagate to the right where an open-circuit-short-circuit combination is used to convert the push-push wave to push-pull, thus reflecting the signal in the open wire transmission line mode back toward the receiving end. The reflected signal drives transformer B in push-pull and appears at the output of coax B. This is the main lobe response of pattern B. This signal is cancelled in transformer A since the push-pull currents cancel, thereby confining pattern B to coax B.

The open-short termination is the simplest way to convert the antenna wave to push-pull. It relies on the fact that a short circuit reflects 180 degrees out of phase, whereas an open circuit reflects in phase. Since the open-short termination always introduces a mismatch between the push-push and push-pull modes, it should normally be replaced with an end transformer which can accurately match the two modes.

By switching from coax A to coax B a signal arriving in lobe 1 of pattern A will be transferred to lobe 4 of pattern B. Because the two patterns are mirror images, the front-to-back ratio (FBR) of the antenna can be measured by

BASIC STEERABLE WAVE ANTENNA

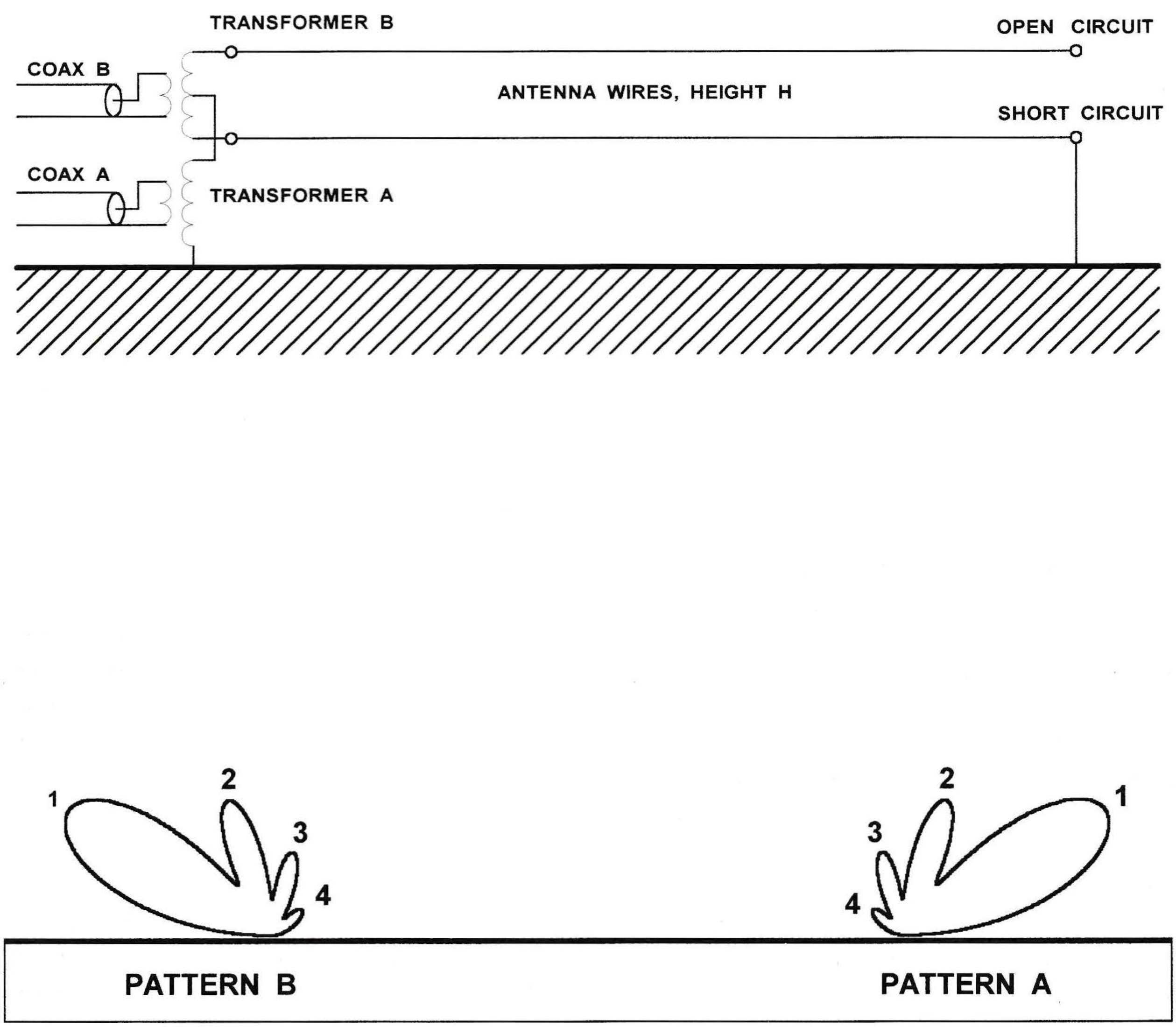


Figure 15.

simply switching from coax A to coax B and reading the decibel change in signal level.

4.1 NULL STEERING

Null steering is useful in rejecting high level interference in communications channels. It can achieve an extremely high FBR at a specific arrival angle at the same time enhancing the FBR over a range of angles near the null itself. It is clearly superior to the single wire antenna using the CONE OF SILENCE mode because the parameters are under operator control. The null controls can compensate for construction errors, measurement errors and, to a degree, coupling to other antennas. The null is steered electrically, thus avoiding the use of costly and cumbersome mechanical equipment to rotate antenna structures.

Basically the null is formed by combining the signals in the two patterns in such a way that cancellation occurs at a specific arrival angle called the NULL STEERING ANGLE. A null steering exercise is carried out in figure 16. An interfering signal is arriving in lobe A2 of pattern A. In order to form a null at the arrival angle of the interference the following procedure is used:

1. Reduce the amplitude of lobe B1 in pattern B to equal the amplitude of lobe A2 at the arrival angle of the interference.
2. Adjust the phase difference to 180 degrees.
3. Sum pattern A and B to form the null.

The null formed by the above process is shown in the lower part of figure 16. The process of summing out-of-phase signals is the same as subtraction of in-phase signals. The steerable null pattern in figure 16 can be thought of as the result of subtracting the shrunken version of pattern B from pattern A. By swapping the A and B inputs to the nulling circuit the null is switched to the right, forming a mirror image of the null pattern of figure 16. In this case lobe B1 would be maximized and lobe A1 minimized.

The formation of the steerable null adds an extra lobe to the basic SWA because of the lobe-splitting action of null steering. This occurs because lobe B1 does not have the same shape or phase characteristic as lobe A2, hence a true null can form only at the angle where the amplitudes are set equal and out of phase. Note that the steerable null has little effect on the main lobe, A1. Height above ground does not affect the direction of the null in the case of an antenna parallel to flat ground.

In the case of an ideal lossless SWA the phasing problem is minimized because patterns A and B are either in phase or 180 degrees out of phase. This theoretically permits null steering by simply controlling the amplitude ratio of the combined signals. A real SWA, however, will inevitably be lossy to some extent. The losses generally cause deviations from the simple 0-180 degree phase relation and create a requirement for a phase control in addition to the

STEERABLE NULL FORMATION

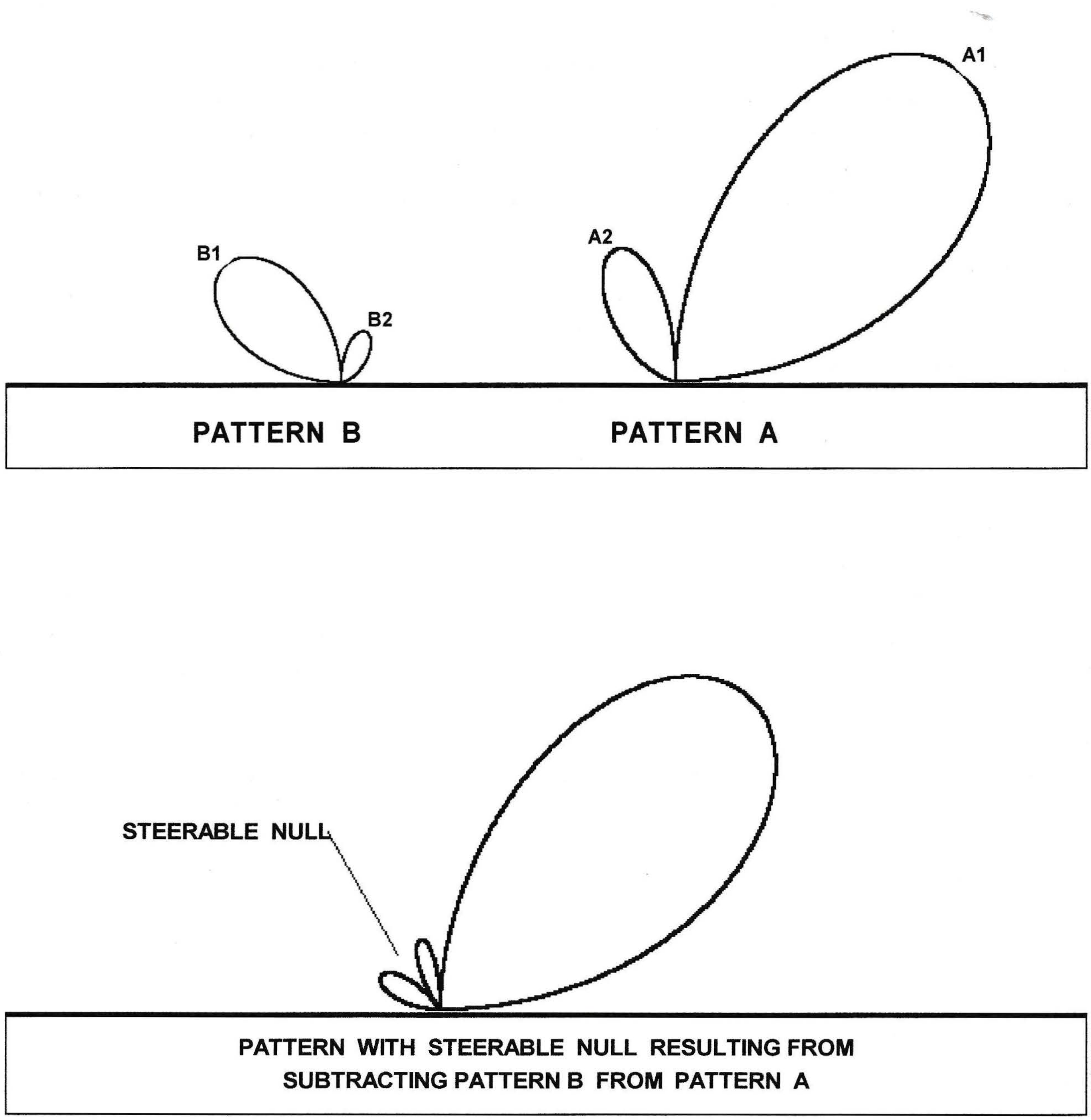


Figure 16.

amplitude ratio control in the null steering network.

4.11 END-FED STEERABLE WAVE ANTENNA

The end-fed SWA as shown in figure 15 has inherently asymmetrical phase characteristics because of the extra phase delay introduced into output B by the transmission line mode of the antenna. For example, if the SWA were cut to a COS length of .54 wavelengths (free space), the open wire transmission line mode of the antenna would have an electrical wavelength of .557 wavelengths (.54 divided by the open wire transmission line velocity factor of .97). In order to use a simple null steering circuit the phase should be corrected to the nearest multiple of 180 degrees or 0 degrees. In this example this can be done by adding .057 electrical wavelengths of coax to coax A in figure 15. This would reduce the delay difference to .5 wave = 180 degrees. The phase shift would remain at 180 degrees for harmonic frequencies, simplifying null steering for harmonically related amateur bands.

Such compensation is unnecessary if the advanced null steering circuit described later is used. The center-fed SWA, by virtue of its inherent symmetry does not need a compensation delay.

4.2 THE CENTER-FED SWA

The center-fed SWA is a design which is completely symmetrical. The basic diagram is shown in figure 17. Construction schematics are found in chapter 5.

The principle of operation is similar to the end-fed design and antenna patterns are identical. The antenna mode signals propagate from one end of the antenna to the other without appearing at the outputs A or B since the push pull transformers provide a zero impedance path for in-phase (push-push) antenna currents from one side of the antenna to the other. In order to appear at an output the antenna mode signals must first be converted to push-pull by reflection from an open-short termination. A signal arriving from the right propagates in push-push to the left, is ignored by the transformers, and proceeds to the left end where it is converted into a push-pull transmission line mode signal. This signal drives transformer A and appears at output A. Non of this signal is transferred out of the center-tap to the other side of the antenna. A signal arriving from the left undergoes a similar process and is delivered to output B. Null steering is the same as in the end-fed SWA, the null steering circuits being interchangeable. The center-fed SWA makes it possible to set up a completely symmetrical antenna. In many cases the center is more accessible than the ends and will save on feeder length.

4.3 TYPICAL PATTERNS

SWA patterns showing typical null steering performance at lengths of .54 wave (COS), 1.08 wave (2xCOS) and 1.62 wave (3xCOS) are plotted in figures 18, 19, 20, 21 and 22. The basic patterns are shown as dotted traces and the null steered pattern as a solid trace. In figures 18, 19 and 20 null steering produces little effect on the main lobe, but in Figure 21 null steering has

BASIC CENTER-FED SWA

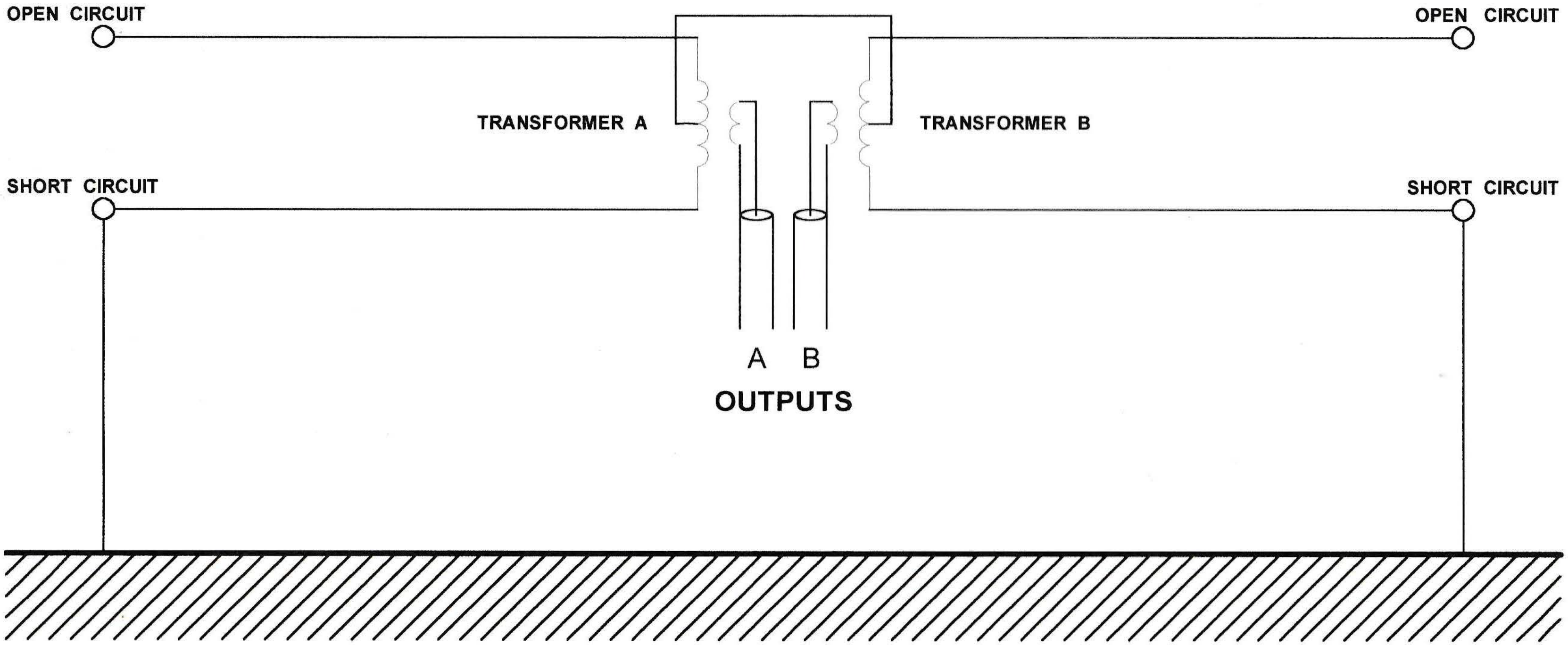


Figure 17

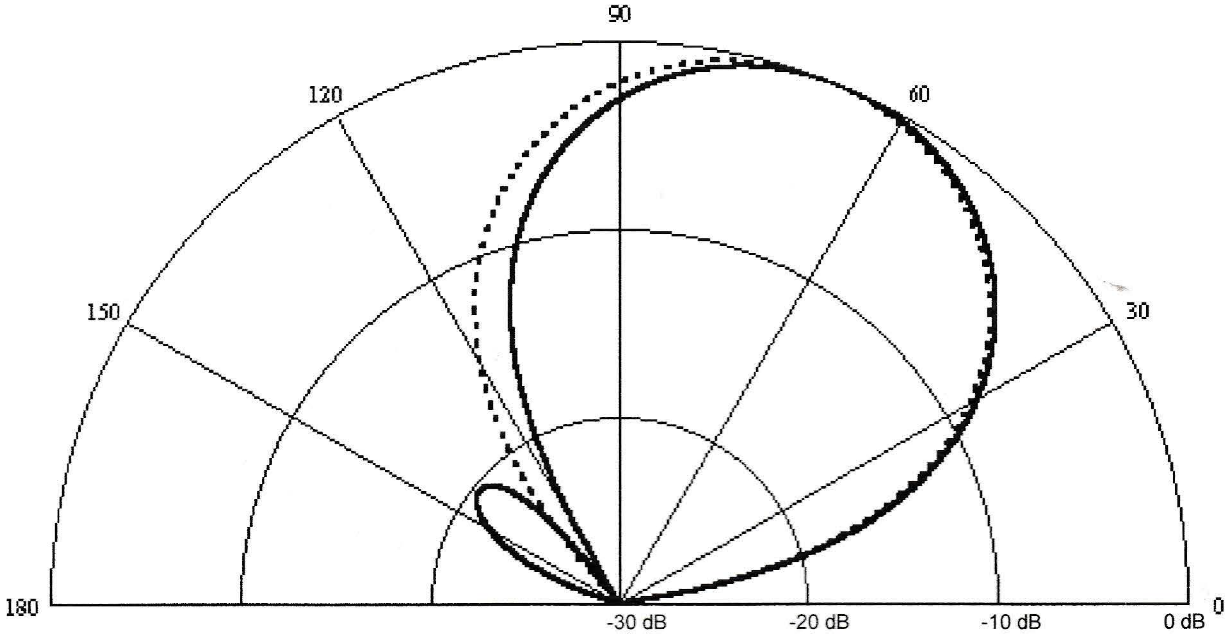


Figure 18.
Dotted trace: .54 wave (COS length) without null steering. **Solid trace: .54 wave with null steered to 123 degrees.** Velocity = .9 Loss factor = .9 Height = .02 wave

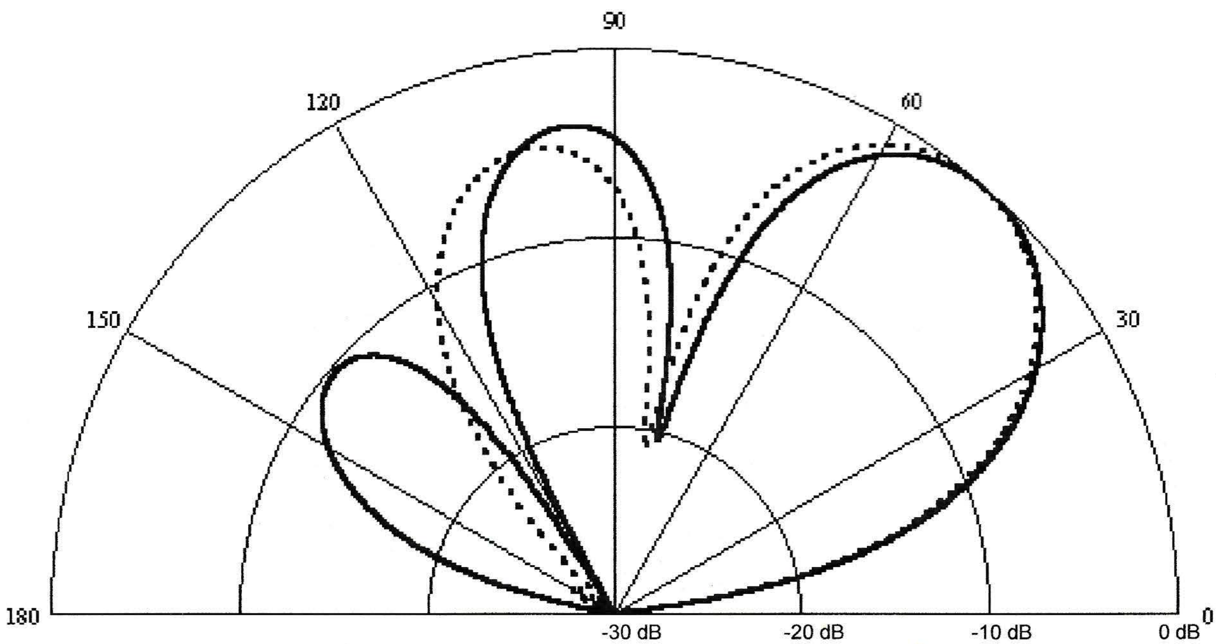


Figure 19.
Dotted trace: 1.08 wave (2xCOS) without null steering. **Solid trace: 1.08 wave with null steered to 120 degrees.** Velocity = .9 Loss factor = .81 Height = .02 wave

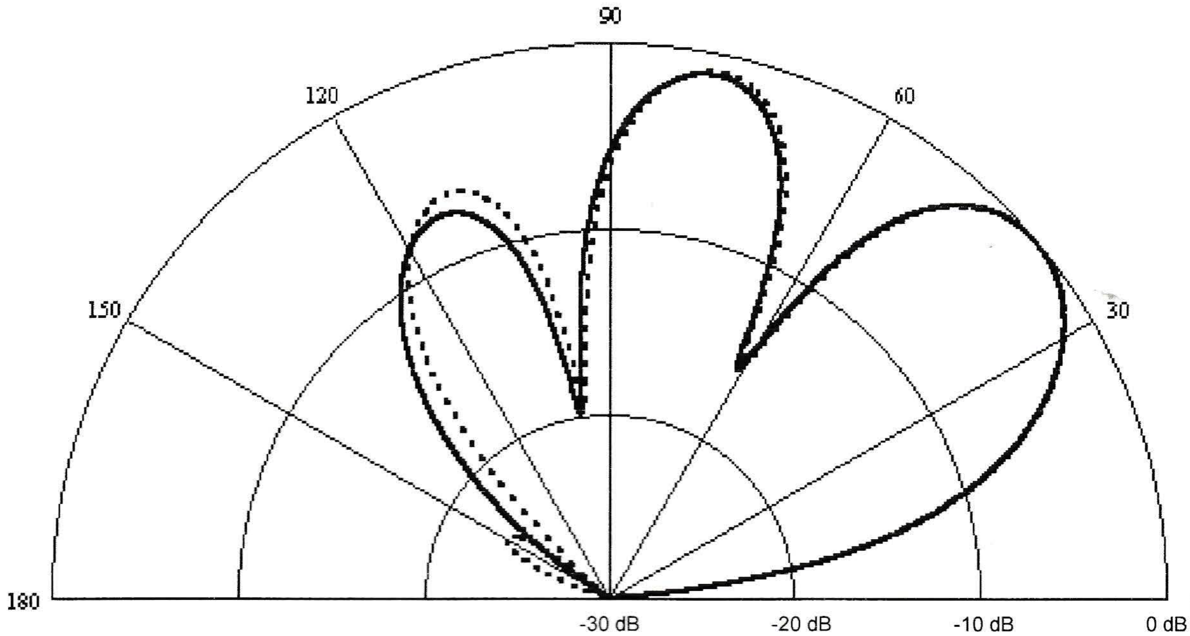


Figure 20.
Dotted trace: 1.62 wave (3xCOS) without null steering. **Solid trace: 1.62 wave with null steered to 150 degrees.** Velocity = .9 Loss factor = .729 Height = .02 wave

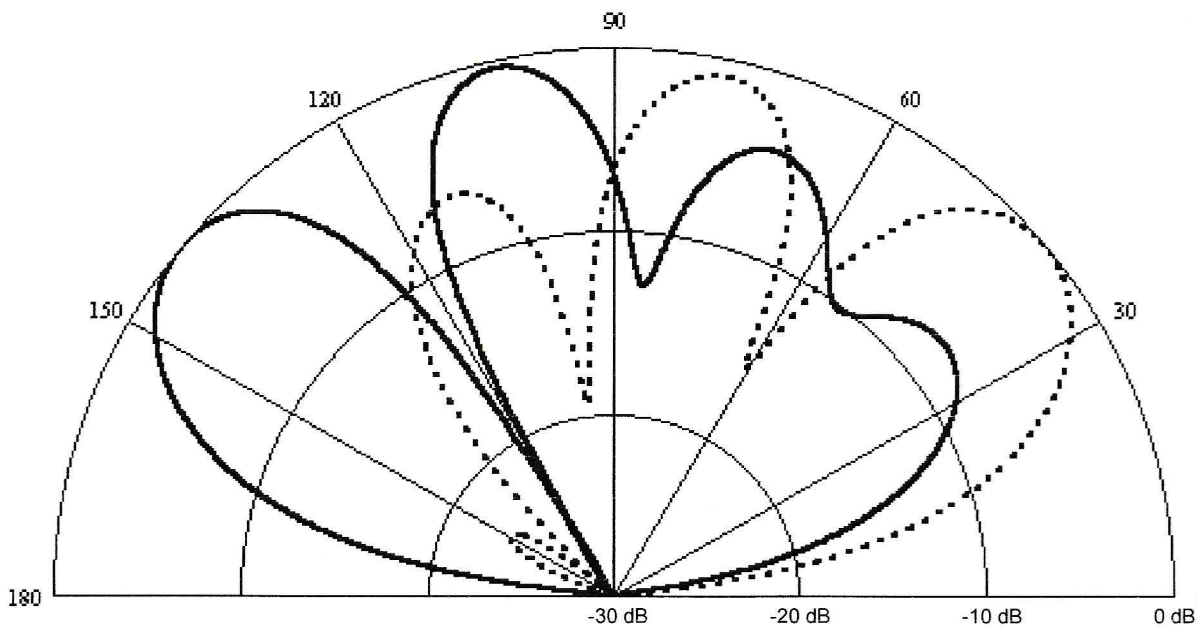


Figure 21.
Dotted trace: 1.62 wave (3xCOS) without null steering. **Solid trace: 1.62 wave with null steered to 120 degrees.** Velocity = .9 Loss factor = .729 Height = .02 wave

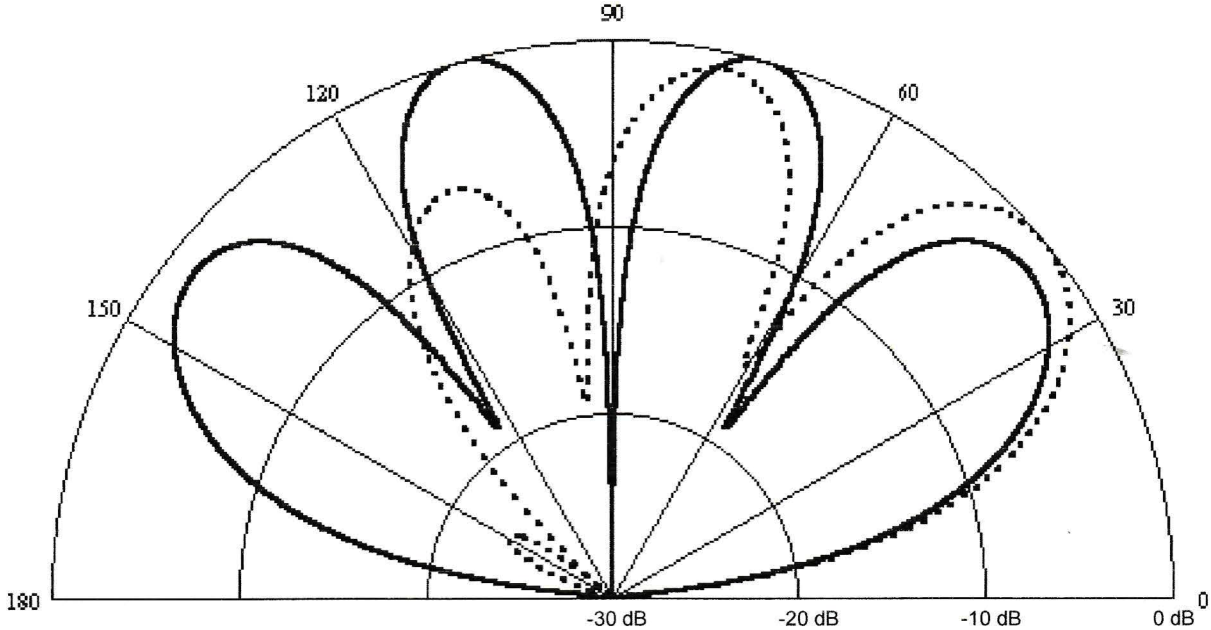


Figure 22.
Dotted trace: 1.62 wave (3xCOS) without null steering. **Solid trace: 1.62 wave with null steered to 90 degrees.** Velocity = .9 Loss factor = .729 Height = .02 wave

reversed the directivity, with the main lobe shifting from 40 degrees to 140 degrees. Here the main lobe and steered null are adjacent instead of being located on opposite sides of the pattern.

In figure 20 the null was steered on the small backlobe at 150 degrees, causing that backlobe to disappear from the chart. This is because the origin of the chart is not zero, but - 30 dB, resulting in the disappearance of lobes which are more than 30 dB below the pattern maximum. Rest assured that the split fragments of the 150 degree lobe, tiny though they are, are still there condensed inside the infinitesimal dot at the origin.

In figure 22 we have steered the null to 90 degrees (broadside), causing the pattern to become bidirectional (FBR = 0 dB at all angles).

The general behavior of null steering is that when the pattern is pinched by a null at one point, it bulges out elsewhere.

4.4 LOSSY SWA'S

The effect of distributed losses on SWA patterns without null steering is identical to the effects noted on single wire antennas in chapter 2. In figure 23 the basic (dotted trace) pattern for a very high loss SWA is shown. The nulls between the lobes are largely filled in and the overall pattern bears a ghastly similarity to the .5 wave (dotted trace) pattern in figure 3. Due to large loss per unit length, the .5 wave closest to the receiving end contributes most of the signal to the output. Thus as lossiness is increased the pattern tends to converge to a half wave pattern. A revolting development, indeed.

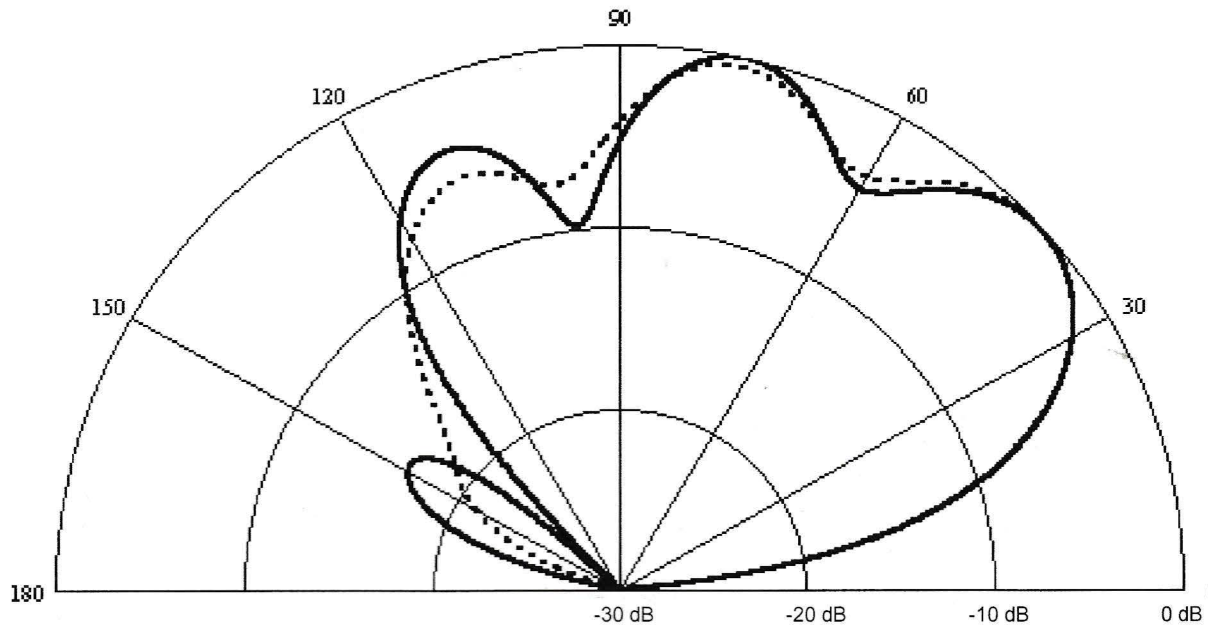


Figure 23.
Dotted trace: 1.62 wave (3xCOS) high loss without null steering. **Solid trace: 1.62 wave high loss with null steered to 135 degrees.**
Velocity = .9 Loss factor = .25 Height = .02 wave

While lossiness causes the nulls between the natural lobes of the pattern to fill in, the steered null is sharp and clean, allowing large scale locally generated noise to be effectively nulled. Null steering can also improve the overall FBR of the lossy antenna.

The longer and lossier the antenna the less stable the null when attempting to null on sky wave signals. This is the most important drawback to long, lossy SWA's. Because of the the exponential decay of signal contribution along the antenna, the most effective signal gathering portions of the two antenna patterns will concentrate near opposite ends of the antenna. This causes a space diversity effect between pattern A and pattern B, causing signals to fade independently in the two patterns. A stable null cannot be formed by subtracting independently fading signals. The effect can be reduced by reducing antenna length, by reducing end-to-end loss or a combination of these measures.

4.5 THE MICRO SWA

The MICRO SWA is designed for locations with space restrictions (e.g., small urban lots) with high electrical noise where long antenna runs are not feasible. I define a MICRO SWA as one which is approximately a quarter wave or less in length. Initially I considered such short antennas to be substantially useless in applications demanding directivity because the pattern tilt on such short antennas is very slight. In the absence of null steering the FBR approaches one-to-one in all directions. The pattern of a .1 wave MICRO SWA is shown in figure 24 (dotted trace). Hardly a useful antenna the way it stands. However, by experimenting with the null steering equations at short lengths it became

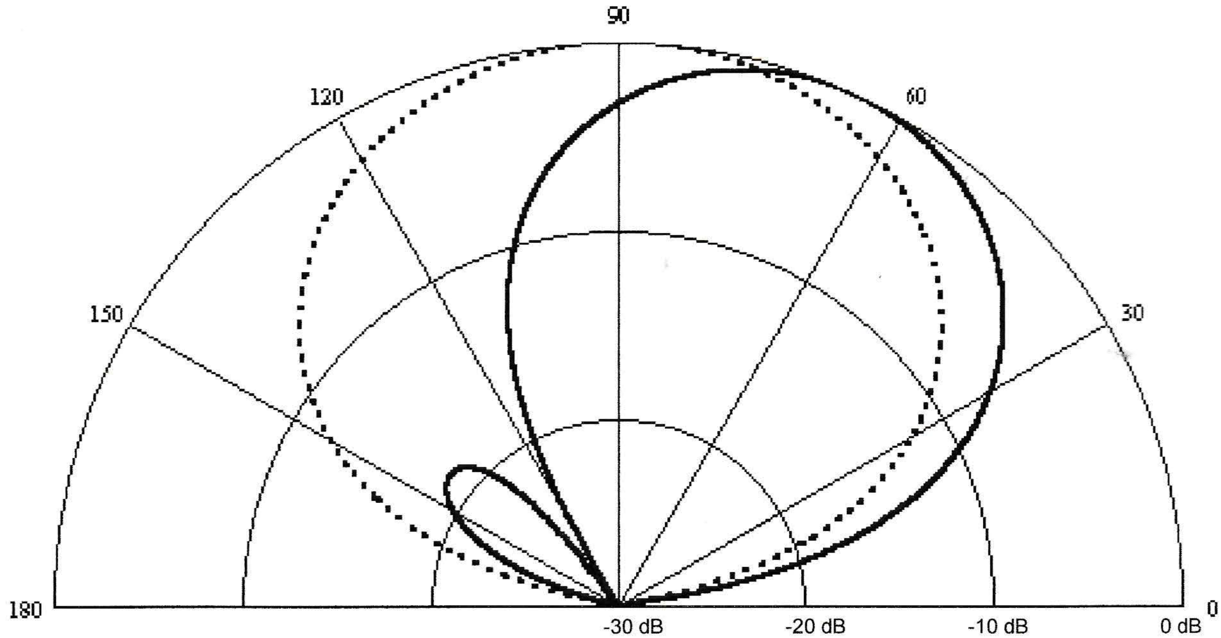


Figure 24. MICRO SWA

Dotted trace: .1 wave is nearly non-directional.
Solid trace: .1 wave with null steered to 123 degrees.

Compare this to figure 18.

Velocity = .9 Loss factor = .98 Height = .02 wave

clear that in spite of the small difference in pattern tilt between the forward and reverse patterns, the subtractive process of null steering produces a directivity pattern very similar to that of a full half wave antenna. This is demonstrated in figure 24 with a null steered to 123 degrees. The resulting pattern is comparable to the pattern for a .54 wave antenna with a null steered to 123 degrees as shown in figure 18.

The price for such directivity is loss of signal level from all directions due to the subtraction process between two nearly equal patterns causing a great deal of cancellation. The problem is further exacerbated by the fact that a short SWA captures less signal before the subtraction process for null steering even begins to cause cancellation.

While this antenna is not a great DX antenna, it is inexpensive, easy to maintain and has a number of important uses:

1. Nulls out locally generated interference.
2. Can be fitted on small city lots.
3. Useful in broadcast band listening where signals are strong. Co-channel stations can often be nulled out.
4. Wideband operation for short wave listening. Helpful in reducing jamming, co-channel interference, locally generated noise.
5. If nulling is not needed, then the two patterns can be added rather than subtracted to increase signal levels.

Construction details are provided in chapter 5.

4.6 THE MICROSLO

The MICROSLO is the slow wave version of the MICROSWA. It is designed to overcome the main deficiency in the MICROSWA, namely the small difference in tilt angle between the two patterns. The increase in pattern tilt is brought about by using a zig-zag slow wave antenna structure (see figure 36) instead of the straight wire normally associated with wave antennas. A substantial increase in signal pick-up (8-9 dB) in the null steered mode results compared to the MICROSWA, rendering the MICROSWA obsolete. The improvement in directivity brought about by slowing the velocity on a .4 wave antenna is shown in figure 7. The MICROSLO directivity pattern shape with null steering is virtually the same as that of the MICROSWA (figure 24), but with greatly increased signal pick-up because of the decrease in cancellation. The zig-zag design also decreases the problem of selecting an end termination because this is already settled by the geometry of the antenna. In the design shown in figure 36 the velocity factor turns out to be the antenna length (70 feet) divided by the wire length (120 feet) or v = .58. This relationship cannot be expected to hold true as a general rule for all geometries, but is apparently true for this particular geometry. I believe that the MICROSLO is the most important advancement in wave antenna design presented here in the third edition of the BEVERAGE ANTENNA HANDBOOK. It opens the possibilties for many innovative slow wave designs which could evolve into serious competition for longer, more traditional straight wire antennas. At present slow wave structures are useful only in upgrading the performance of short (less than .5 wave) null steered SWA's due to limitations cited in section 2.4.

4.7 PERTURBATION CONTROL

Wave antennas are sometimes situated in locations where they exhibit mutual coupling to nearby antennas, power lines or metal structures. This type of coupling can radically distort the directional characteristics. With null steering in place it may still be possible to steer a null on an undesired signal in the presence of mutual coupling provided the mutual is not excessive. In the case of locally generated noise from a fixed direction a sharp null is still possible, but the null steered on sky-wave signals is likely to be shallow and unstable because the antenna or other object causing mutual coupling is unlikely to be co-polarized with the wave antenna. In this case the constantly shifting polarization of the sky wave would destabilize the null. In general null steering can decrease, but not completely compensate for externally induced perturbations.

Grounded quarter wave verticals or inverted ells are particularly effective in ruining SWA directivity. These offending antennas can be defanged by ungrounding them, thus making them anti-resonant, when using the SWA. Every effort should be made to make all nearby antennas non-resonant on the band on which the SWA is in use by detuning during the receive cycle.

4.8 SWA IMPEDANCE CALCULATIONS

The push-pull (transmission line mode) and push-push (antenna mode) impedances of a two wire SWA with the wires side-by-side (equal height) above a perfect ground can be calculated if wire diameter, height above ground and wire spacing are known. Use equ 2.6 for calculating wire diameter from the wire AWG size.

The push-push impedance of the SWA above perfect ground is given by:

equ 4.0
$$Zoa = 69 \log_{10}\left[\frac{4h}{d}\left[1 + \left[\frac{2h}{D}\right]^2\right]^{1/2}\right]$$

The push-pull impedance of the SWA above perfect ground is given by:

equ 4.1
$$Zot = 276 \log_{10}\left[\frac{2D}{d}\left[1 + \left[\frac{D}{2h}\right]^2\right]^{-1/2}\right]$$

In equ 4.0 and 4.1 the terms are defined as follows:

D is spacing between wires.
d is diameter of wire.
h is height above ground.

All of the above terms must be expressed in the same units, e.g., inches, feet, centimeters, etc. Mixed units of length give erroneous results.

The above computations can be done on inexpensive scientific hand-held calculators.

5 STEERABLE WAVE ANTENNA CONSTRUCTION

The basic diagram of the SWA is shown in figure 15. There are many variants of this simplified diagram although the theory of operation remains the same.

Figure 15 shows two typical (2 wavelength antenna) directional patterns avilable at the outputs, coax A and coax B. The addition of null steering controls permits the operator to generate a steerable null on the backlobes of either pattern. The process of null steering is explained in figure 16.

Each specific antenna design described in this chapter will operate on three amateur radio bands, namely 160, 80 and 40 meters.

5.1 ANTENNA SITE CONSIDERATIONS

Before beginning construction of a SWA or wave antenna check the following list of considerations.

1. The site should be flat as possible. A sloping site is fine, although the antenna will favor signals from the downhill direction.
2. The layout should allow the antenna to run in a straight line. If the ground under the antenna rises and falls the antenna should remain straight, thereby minimizing the degradation in performance caused by the uneven ground. The scattering caused by uneven ground can be further minimized by running the ground wire(s) parallel to the antenna, even if the ground wires must be several feet above ground in places. The installation of several parallel ground wires equally spaced around the central ground wire will help create a virtually flat electrical ground plane.
3. The coaxial cable should lie on the ground or below the surface to avoid radiation pick-up. Double shielded or solid shield (hardline) coaxial cable is necessary, especially for long runs. In cases where the feeder cables run side-by-side for a long distance considerable cross-coupling can occur between cables if single shield cable is used. The best way to avoid this is to use hardline. On double shield cable keep the two cables separated by at least one foot.

5.2 ANTENNA IMPEDANCE CONSIDERATIONS

There are two impedances of concern in the SWA, the antenna mode characteristic impedance, Zoa, and the transmission line mode impedance, Zot.

The antenna mode impedance is the characteristic impedance of two parallel wires over ground over the ground plane operating in phase (push-push). This is the mode which picks up signals.

The transmission line mode impedance is the characteristic impedance of two parallel wires over ground operating in push-pull (out of phase).

This mode transmits signals reflected from the end termination back to the receiver.

The signals in the two modes propagate in opposite directions on the wires and are linearly superimposed. Linear superimposition implies that there is no interaction between signals and modes, thus allowing the simultaneous pick-up of thousands of signals without crossmodulation or distortion.

A knowledge of Zoa and Zot are necessary for the calculation of turns ratios in matching transformers and end terminations. Zoa and Zot can be calculated using equ 4.0 and 4.1 in section 4.8. Of these equations, 4.0 is the least accurate because most antennas are set up over imperfect ground. Table VI is provided below to show examples of impedance calculations for typical antennas.

TABLE VI

SWA IMPEDANCES Height above ground = 7 feet. Wire size = #14 AWG			
Wire spacing inches	Push-push impedance Zoa	Push-pull impedance Zot	Zot/Zoa
6	357	627	1.8
12	336	710	2.1
18	324	758	2.3
24	315	792	2.5
36	303	839	2.8
60	289	896	3.1
120	273	962	3.5

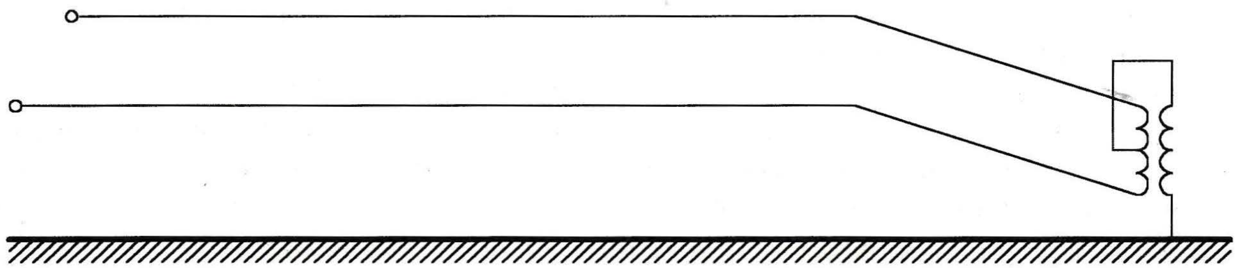
5.3 SWA END TERMINATIONS

End terminations provide the function of transforming the push-push antenna mode signals into push-pull reflections for transmission back to the receiver termination. The open-short termination shown in figure 15 is the simplest. A variety of end terminations is shown in figure 25.

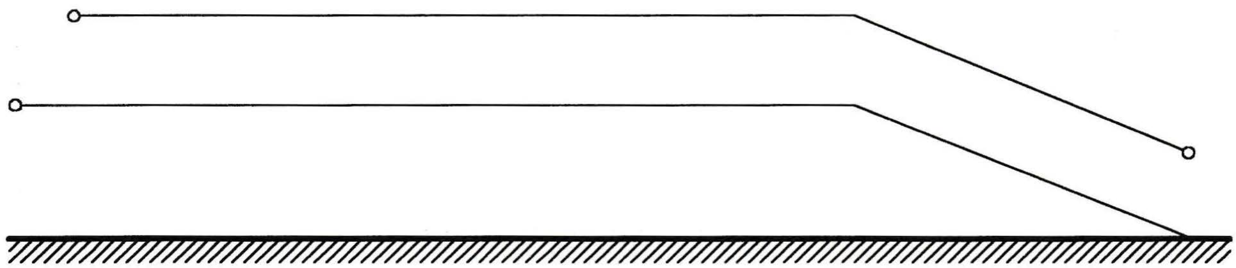
The terminations shown in figure 25 b, c and d are basically open-short (OC-SC) terminations. All of the OC-SC terminations suffer from some degree of mismatch between the transmission line mode and the antenna mode. In theory they can only provide a perfect match if Zot / Zoa = 4. Table VI shows Zot / Zoa = 2.1 for a 12 inch wire spacing. I do not recommend using OC-SC terminations with wire spacings less than 12 inches.

5.31 END TERMINATION TRANSFORMERS

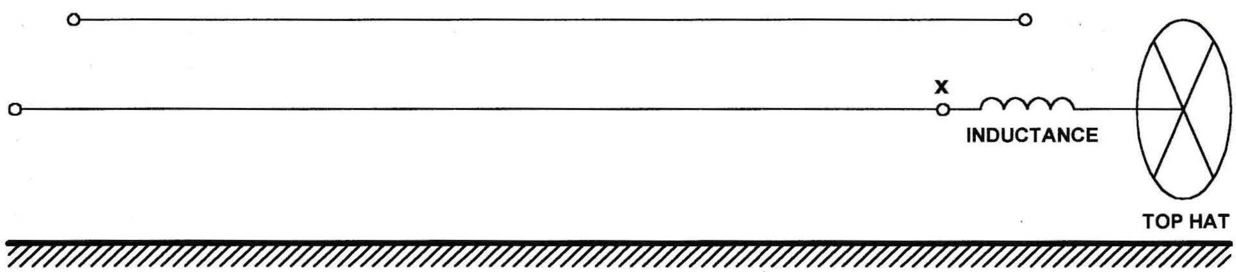
SWA END TERMINATIONS



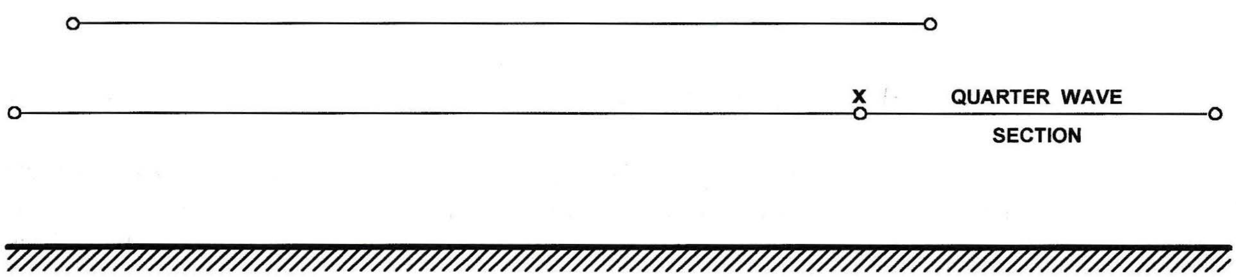
a) SLOPING TERMINATION WITH TRANSFORMER



b) SLOPING OC-SC TERMINATION



c) CAPACITY HAT TERMINATION



d) QUARTER WAVE TERMINATION

Figure 25.

End termination transformers are designed to match the SWA antenna mode to the transmission line mode. A schematic for this is shown in figure 25 a. The push-push antenna mode currents are summed at the transformer center tap and fed to the primary winding on the right. The output winding on the left then drives the transmission line in push-pull. Matching is accomplished by selecting the appropriate turns ratios.

The transformer is wound on a half inch diameter ferrite toroid using thin insulated wire as described in many tables and antenna diagrams in this book. Frequency range, insertion loss, core stacking and recommended wire are discussed in section 3.3.

The traditional Beverage end transformer in figure 25 a is shown because it is conceptually easy to understand. However, it occurred to me that this transformer has an autotransformer equivalent which is easier to construct, although harder to understand. In computing turns ratios it is easier to use the traditional transformer and then to convert the result into the autotransformer equivalent by using the information in figure 26. All of the end transformers shown in the antenna diagrams are autotransformers. If you want an optimum match and higher efficiency, use end transformers.

5.32 SLOPING TERMINATIONS

The sloping termination of figure 25 b is a simple wideband termination in which one wire is shorted to ground. I have used this termination for many years with great success even though it presents some mismatch between the transmission line mode and the antenna mode. The sloping section makes an angle with ground of 10 degrees or less. This is the termination to use to give an antenna a quick try, since it is easy to retrofit later with a transformer.

By using end transformers it becomes practical to use 300 ohm ribbon line, 72 ohm twinlead or coaxial cable of any impedance as the antenna instead of open wire line.

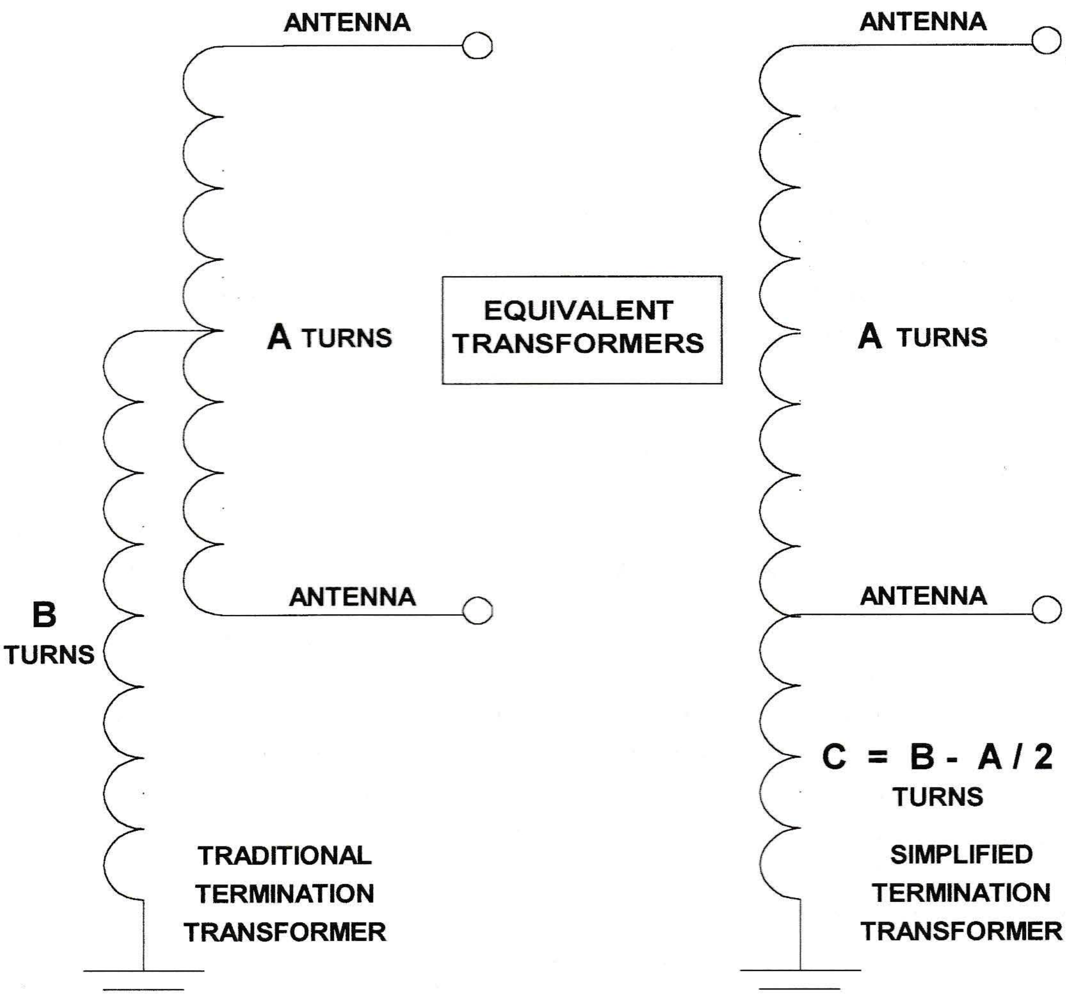
The main reason for a sloping termination is that it avoids the use of a vertical downlead whose omnidirectional pick-up would pollute the directivity of the antenna.

5.33 CAPACITY HAT TERMINATION

. The capacity hat termination is shown in figure 25 c. This is a variant of an OC-SC termination. The inductance is chosen to resonate with the capacity hat at the operating frequency. At resonance point X is a short circuit. This termination has the following advantages:

1. It does not require a ground return, thus it reduces distortion of the antenna pattern.
2. It is compact.

SIMPLIFIED END TERMINATION TRANSFORMER



TO USE THE SIMPLIFIED TRANSFORMER:

1. Calculate the primary (A) and secondary turns (B) for the traditional transformer.

2. Convert to the simplified transformer using the above relationships. Winding A has the same number of turns in each transformer. Winding C has B - A / 2 turns.

Figure 26.

3. It can be used where a ground system (ground stake, ground wires) are impractical.

The disadvantages are:

1. It is a narrow band device. If multi-band operation is desired, the inductor can be tapped and bandswitched to resonate on the required bands.
2. Like in all OC-SC terminations there is a mismatch between Zoa and Zot.

Coil and capacity hat data may be obtained from top-loading data on short mobile antennas. Resonance may be checked by tying the X end of the inductor to a good ground (a water pipe will probably do) and grid dipping the coil with the capacity hat attached. Adjust the coil turns to resonate on the desired band. A roller inductor is a choice component for this application. The capacity hat will operate over a much wider bandwidth when used in a SWA than on a short mobile antenna because the SWA impedance is much higher, resulting in a lower Q.

5.34 QUARTER WAVE TERMINATION

The quarter wave termination is shown in figure 25 d. The quarter wave extension of one wire causes a short circuit at point X making this another variant of an OC-SC termination.

Advantages:

1. Simplicity. All that is required is extra wire length.
2. It does not require a ground connection, thus can be used without a ground system.

Disadvantages:

1. Requires more real estate.
2. One band operation.

A possible solution for multi-band operation is to cut the termination to a quarter wave on the highest band used, then inserting a tapped coil (or roller inductor) at point X to restore the section to an electrical quarter wave on the lower frequency bands. A section of wire less than a quarter wave in length may be treated as a capacity hat as discussed in the previous section.

Because the extra quarter wave alters the radiation pattern, the quarter wave termination is not suitable for operation in the CONE OF SILENCE mode.

5.35 RIGHT ANGLE TERMINATION

The right angle (RA) termination is shown in figure 27. The suppression of signal pick-up from vertical downlead is very important in the RA design since a vertical section has an omnidirectional pattern which can degrade the overall directivity of the antenna.

RIGHT ANGLE TERMINATION

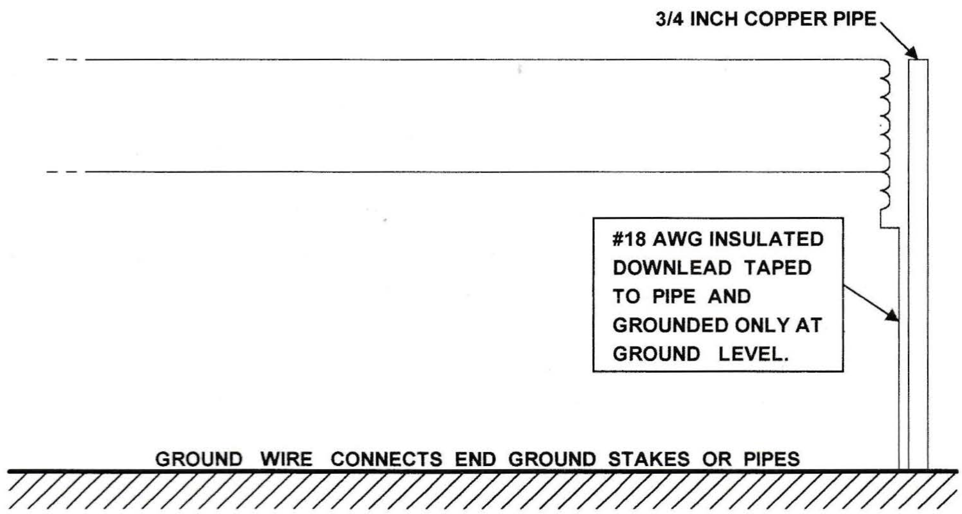


Figure 27.

The downlead is shielded from signal pick-up by taping it to a grounded copper pipe which serves also as an end support for the antenna and the end termination transformer. The larger the diameter of the pipe and the thinner the downlead, the better the shielding.

5.4 SWA RECEIVING TERMINATIONS

The receiver termination transforms the antenna impedance to the coaxial cable impedance and converts balanced antenna outputs to the unbalanced output cables. Two types of receiver terminations are discussed, namely center fed and end fed.

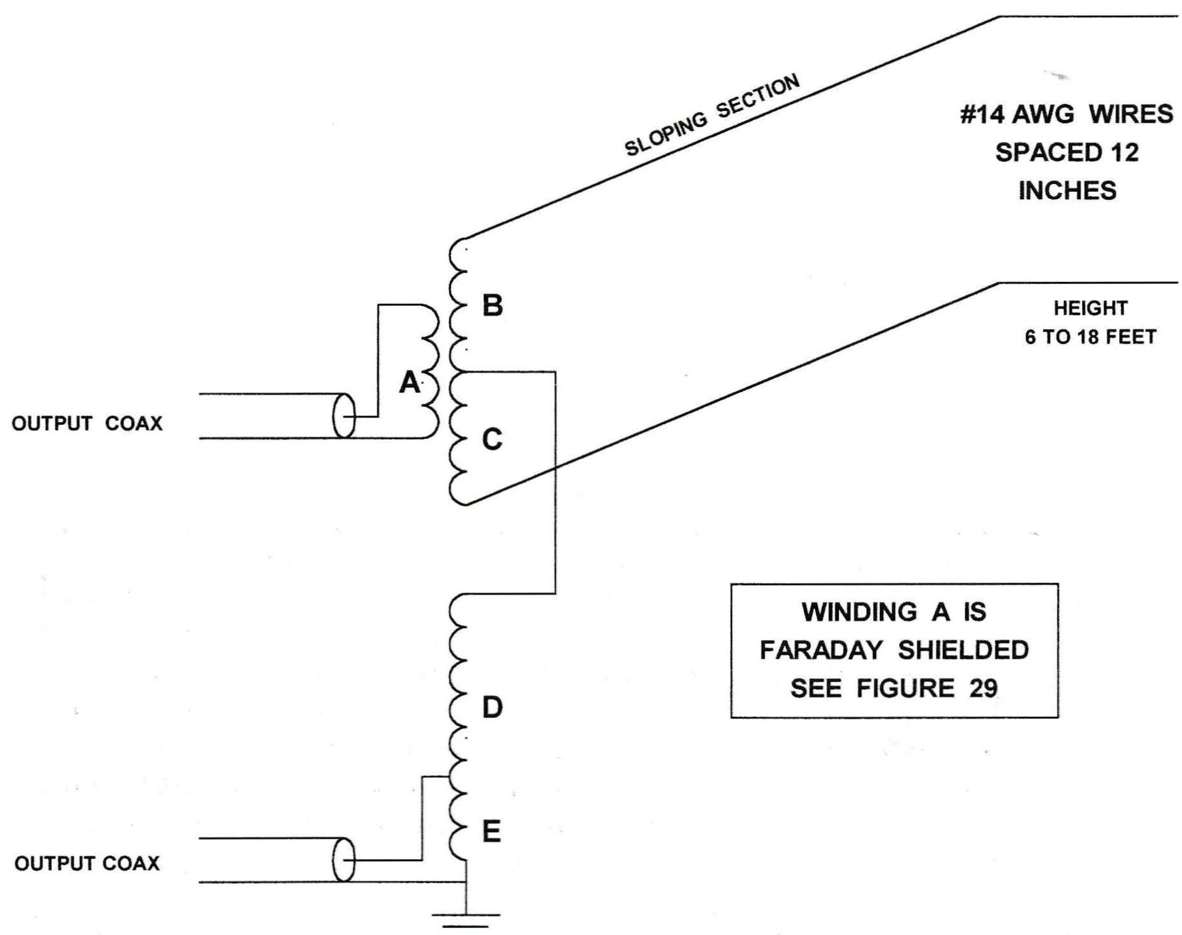
5.41 END FED SWA RECEIVER TERMINATION

The end fed SWA termination has two transformers as shown in figure 28. The upper transformer matches the transmission line mode, Zot, to coax, and acts as an isolation transformer for the balanced-unbalanced conversion. The lower transformer matches the antenna mode, Zoa, to coax. Here an unbalanced to unbalanced transformation is required, ideal for an autotransformer. Turns numbers are given to match either 50 ohm or 75 ohm coax. The match is correct as seen from the antenna, but the impedance seen from the coax is somewhat lower than the nominal coax impedance because of the shunt resistance and reactance per turn squared introduced by the ferrite core. The nominal SWA impedances in figure 28 are:

$$\text{Zot} = 710 \text{ ohms}$$
$$\text{Zoa} = 357 \text{ ohms}$$

Of these two impedances only Zoa varies appreciably with height, thus the

END FED SWA RECEIVER TERMINATION



TURNS FOR 50 OHM OUTPUT:

A = 5T
B = 10T
C = 10T
D = 7T
E = 4T

TURNS FOR 75 OHM OUTPUT:

A = 6T
B = 10T
C = 10T
D = 6T
E = 5T

Figure 28.

FUSE CLIP FARADAY SHIELD

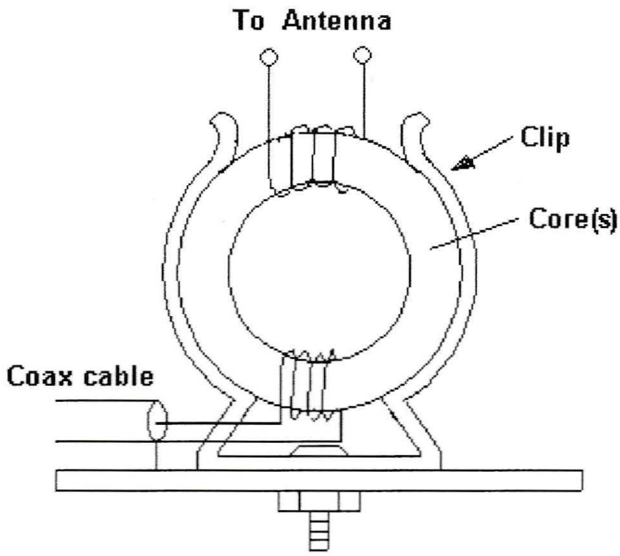


Figure 29.

> We have researched the use of bronze fuse clips to provide Faraday shielding and a snappy mechanical mount for SWA transformers. The fuse clip mounts provide a good ohmic ground for the cores (MN8CX is conductive), greatly reduce capacitive coupling between windings (Faraday shield effect) and can accommodate either single or double core transformers. The clip has a hole in its base to accept a mounting screw. The clip also by-passes lightning induced surges to ground rather than arcing into the output winding where it can raise hob with receiver front ends. Cores gronked by lightning can be unsnapped and replaced. See last page of book for ordering.

Installation Instructions

1. Place one (or two) cores into fuse clip. The tops of the clips may have to be squeezed together before insertion to insure a tight spring fit.
2. The transformer should be wound with the cores in place in the clip. Use #30 AWG kevlar coated wire (see bottom of page 26).
3. Start center-tapped windings at the center. Position the center tap at the center of the winding space and wind outward on each side.
4. To provide Faraday shielding and lightning protection the bronze clip must be grounded. The clip cannot provide total protection from lightning, but can only lessen the probability of damage. DISCONNECT SWA's FROM RECEIVERS AND NULL STEERERS DURING LIGHTNING ACTIVITY AND WHEN NOT IN USE.
5. The MN8CX material is conductive therefore only insulated wire should be used.
6. The clips provide a handy mount for otherwise unwieldy transformers.

upper transformer remains the same for any antenna height above 2 feet.

Since Zoa is a slow function of height the lower transformer would suffer only a 10% mismatch at heights of 6 feet (10% low) and 18 feet (10% high). The receiver termination thus will be quite efficient at antenna heights in the 6-18 foot range.

The sloping section drops one foot per 6 horizontal, just under 10 degrees.

The isolation between pattern A and pattern B can be improved by using a Faraday shield in the upper transformer using the fuse clip mount shown in figure 29.

5.42 CENTER FED SWA RECEIVER TERMINATION

The center fed receiver termination is shown in figure 30. Unlike the end fed termination, it is completely symmetrical. The two transformers are identical, each being matched to the transmission line mode, Zot. Since the transmission line mode impedance is insensitive to height an excellent match can be expected for any height above 2 feet.

In order to avoid capacitively coupling antenna mode signals into windings A these transformers should be wound using the fuse clip mounts shown in figure 29.

300 ohm ribbon, 72 ohm twinlead or coaxial cable may be used instead of open wire line in the antenna. If 300 ohm line or 72 ohm twin lead are used, the wiring diagram of figure 30 is used, but the turns required in the transformers must be changed as tabulated below:

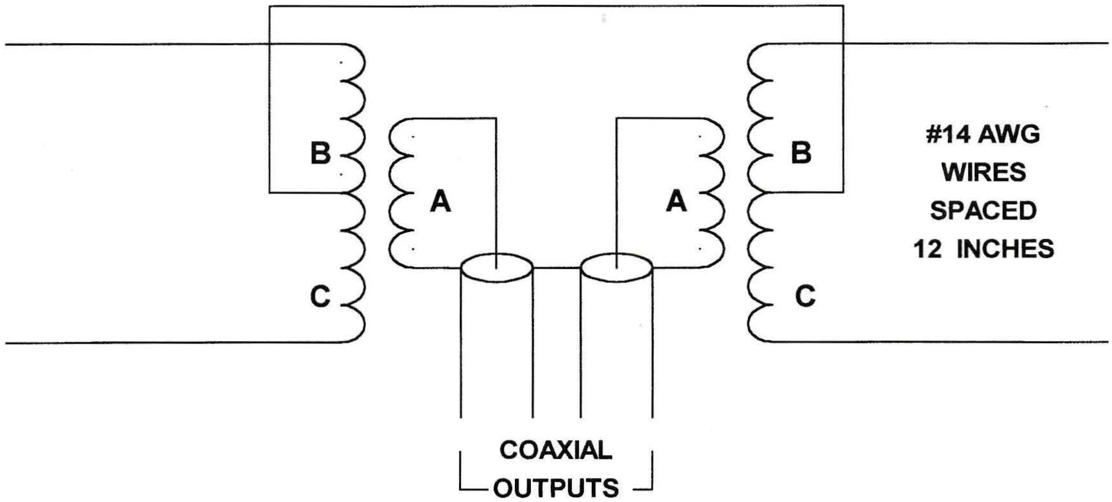
TABLE VII

CENTER FED 300 OHM TWINLEAD SWA		
Transformer Winding	Turns to match	
	50 ohm coax	75 ohm coax
A	6	6
B	7	6
C	7	6

TABLE VIII

CENTER FED 72 OHM TWINLEAD SWA		
Transformer Winding	Turns to match	
	50 ohm coax	75 ohm coax
A	5	6
B	3	3
C	3	3

CENTER FED OPEN WIRE SWA RECEIVER TERMINATION



TRANSFORMERS
FARADAY SHIELD MOUNTED
(SEE FIGURE 29)

TURNS FOR 50 OHM OUTPUT:

A = 5T
B = 10T
C = 10T

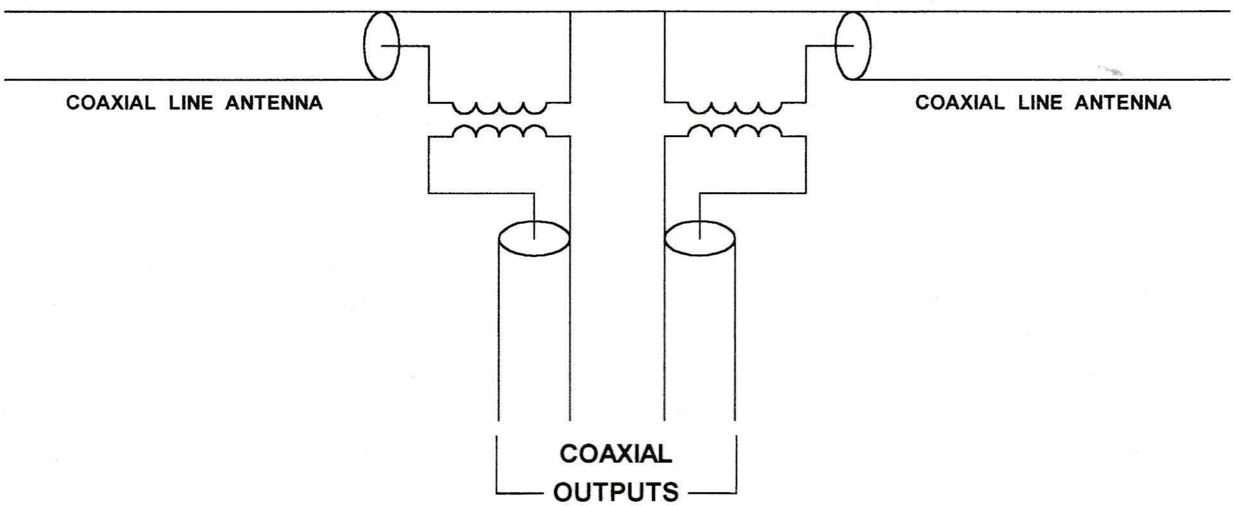
TURNS FOR 75 OHM OUTPUT:

A = 6T
B = 10T
C = 10T

NOTE:
Read section 3.3 page 26
for transformer core info.
See end page for ordering.

Figure 30.

CENTER FED COAXIAL SWA
RECEIVER TERMINATION



TRANSFORMERS
FARADAY SHIELD MOUNTED
(SEE FIGURE 29)

OUTPUT COAX Zo = ANTENNA COAX Zo

ALL WINDINGS HAVE 6 TURNS

Figure 31.

The diagram for the center termination used with a SWA constructed with coaxial cable is shown in figure 31. Here the outer shield of the coax acts as the antenna. If the antenna coax and the output coax have the same characteristic impedance the termination transformers become 1:1, thus all windings have an equal number of turns.

5.5 STEERABLE WAVE ANTENNA CONFIGURATIONS

The two basic configurations of the SWA are the end fed (figure 32) and center fed (figure 33). The SWA is constructed out of transmission line which performs the dual function of picking up signal as an antenna and transmitting it to the output cables. The configurations of figures 32 and 33 are suitable for construction with open wire line, 300 ohm ribbon or 72 ohm twinlead. If coaxial cable is used as the antenna the configuration changes to the diagram of figure 34.

Another variation is the mounting of open wire antenna wires

one-over-the-other rather than side-by-side. Side-by-side results in better balance to ground, but one-over-the-other makes construction simpler. I use both methods interchangeably.

The coaxial cable used to feed wave antennas should be either double shielded or solid hardline (best). Single shielded is notorious for picking up stray signals, especially in long runs. Two single shielded cables lying next to each other over a long run can cross couple signal one to the other. The coax should lie flat on the ground and should be grounded at both ends.

5.51 GROUND SYSTEM

A simple ground system is recommended, but not absolutely necessary for all SWA designs presented in this book. The ground sytem design is common to all SWA configurations.

Each end of the antenna terminates on a ground stake, which can also serve as a mounting post for a transformer box. A heavy insulated wire runs directly under the antenna and is connected to each ground stake. The heavier the wire the better. In order to reduce end-to-end loss other ground wires may be added parallel to the central ground wire symmetrically spaced on each side. These may also be terminated on ground stakes and must run the full length of the antenna. The stakes may be connected together electrically at each end. Try a spacing of 3 feet. I have used ground wires ranging in size from #8 AWG insulated aluminum to #0 AWG insulated aluminum. The wire came from a local metal scrap dealer. Scrap dealers usually charge less for insulated scrap wire. Fortunately it is also more efficient.

The benefits of a good ground systen are described in section 2.1. Here are some ground system mistakes which can ruin directivity:

1. Unsymmetrical radials around a ground stake.
2. Ground stake connected to a chain link fence.
3. Ground stake not parallel to the antenna attached to a ground stake in a random direction.
4. Any asymmetry in the ground system.

Ground wires which are not co-polarized with the antenna can drive the ground stake with spurious pick-up which can appear at the antenna outputs and degrade directivty. This problem is made worse by poor soil conductivity.

5.52 CHOOSING LENGTH

Read section 2.95 and select a multliple of the COS length shown in table IV. To make the selection the velocity and loss factor have to be determined. If you are unable to make these measurements, estimate the velocity using equation 2.4 and use a loss factor of .7. For general DX use I would choose a length three times the COS length shown in table IV. Property restrictions may restrict

the length to lower COS multiples or even to ultra-short lengths such as the MICROSWA and the slow wave MICROSLO which are discussed in sections 4.5, 4.6, 5.57 and 5.58.

5.53 END FED SWA

The end fed SWA layout is shown in figure 32. The turns data on the receiver termination are shown in figure 28 with accompanying text in section 5.41. An OC-SC termination may be used instead of the end transformer to speed construction. A transformer retrofit can be added later.

5.54 CENTER FED SWA

The center fed SWA layout is shown in figure 33. If 300 ohm ribbon or 72 ohm twinlead is used, then appropriate changes must be made in all transformers. Section 5.42 discusses the receiver termination transformers in detail for all varieties of transmission line used in the antenna.

OC-SC terminations may be substituted for the end transformers in figure 33, however the OC-SC is unsuitable for use with 300 ohm ribbon or 72 ohm twinlead because of the large mismatch.

The turns requirements for the end transformers are tabulated in table IX. Windings A and B are shown in the detail insert in figure 33.

TABLE IX

END TRANSFORMER DATA				
	ANTENNA TYPE			
WINDING	OPEN WIRE	300 OHM LINE	72 OHM TWINLEAD	RG-58 COAX
A	18T	12T	8T	6T
B	4T	10T	18T	19T

The coaxial cable version of the center-fed SWA is shown in figure 34. This configuration differs from the others in the fact that the antenna mode and the transmission line mode are not linearly superimposed as in the wire versions. The antenna currents flow only on the outside of the outer braid while the transmission line mode is contained entirely inside the coax. This simplifies the receiver termination transformers as indicated in section 5.42.

5.55 SNAKES........COAX ON THE GROUND

Snakes, a name coined for coax antennas lying in the grass, have achieved a degree of notoriety among 160 meter enthusiasts. The center fed coaxial SWA is an ideal configuration for those who wish to experiment with antennas laid on the ground because the center fed receiver termination is completely unaffected by height above ground or even direct contact with ground.

END FED STEERABLE WAVE ANTENNA

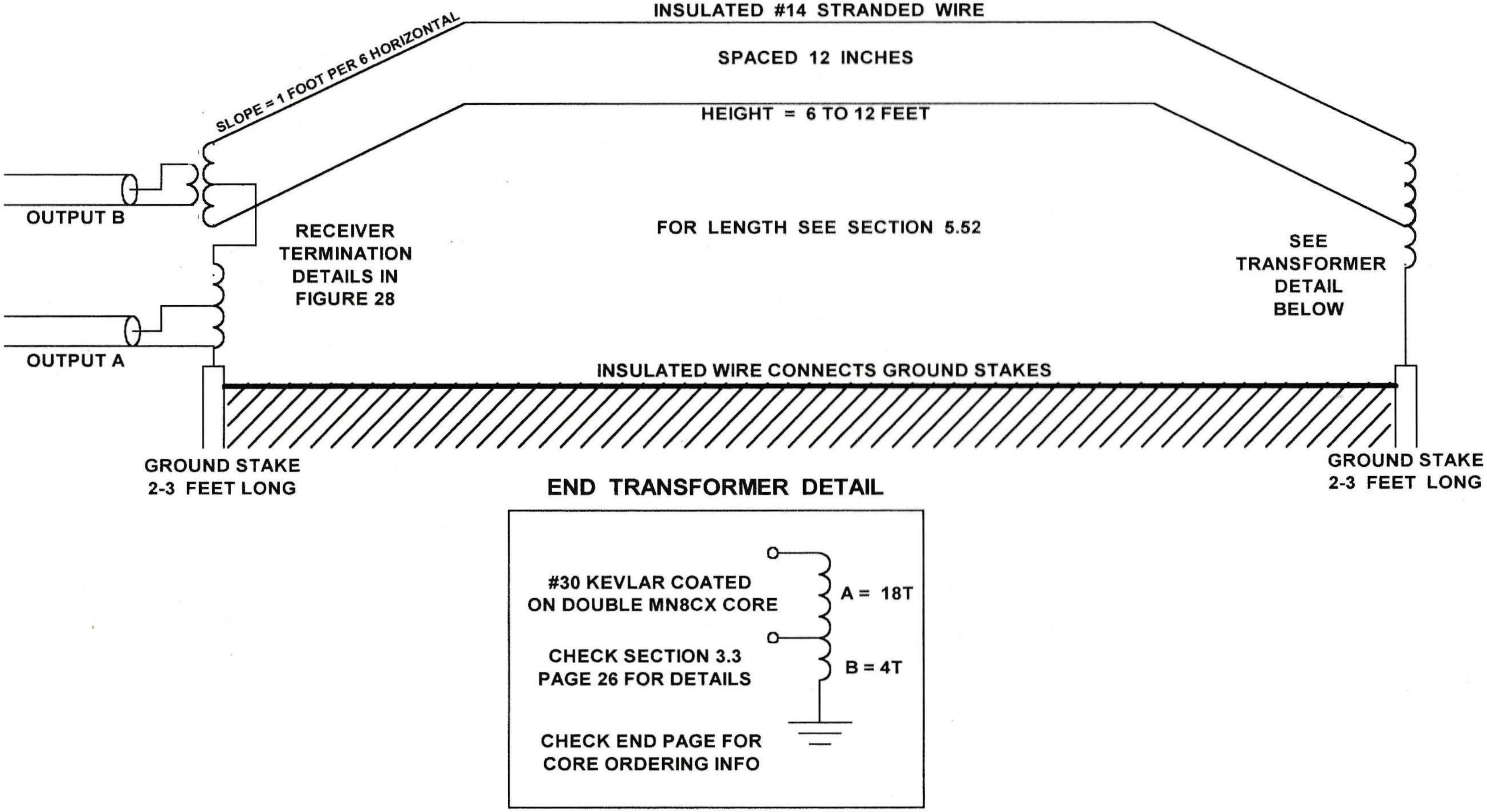
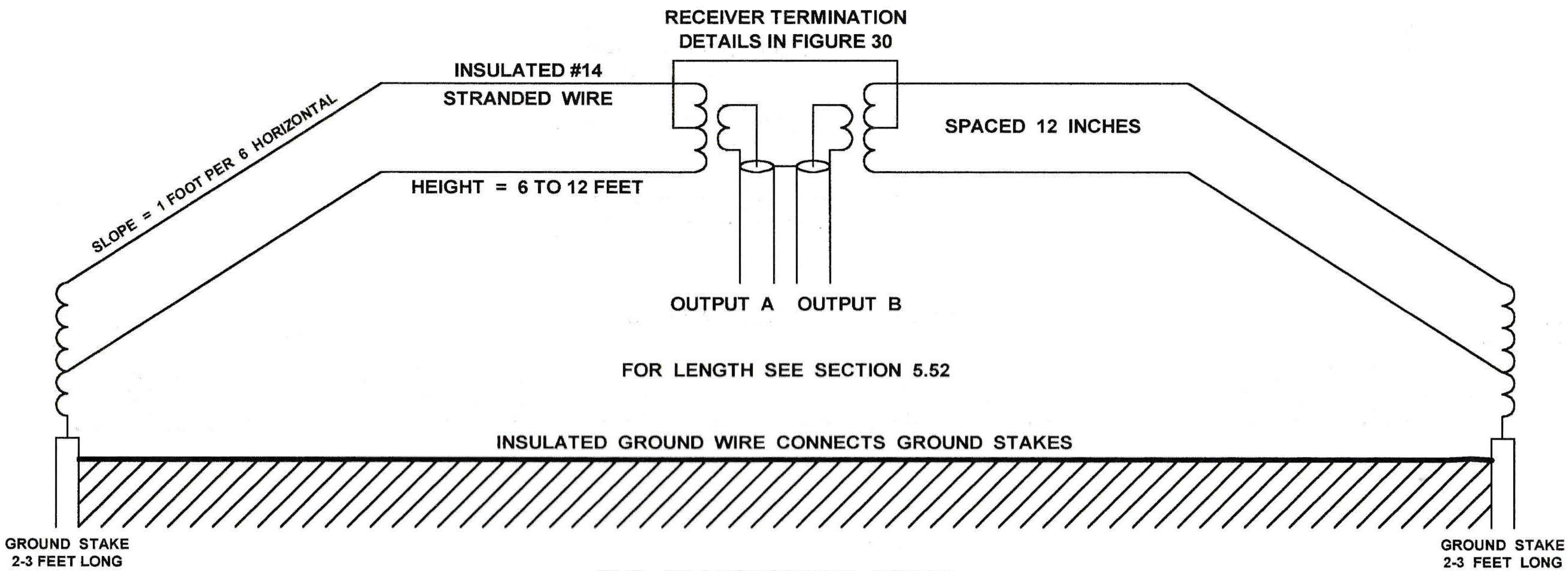


Figure 32.

CENTER FED STEERABLE WAVE ANTENNA

OPEN WIRE LINE VERSION



END TRANSFORMER DETAIL

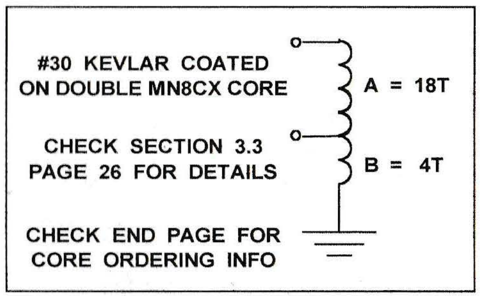
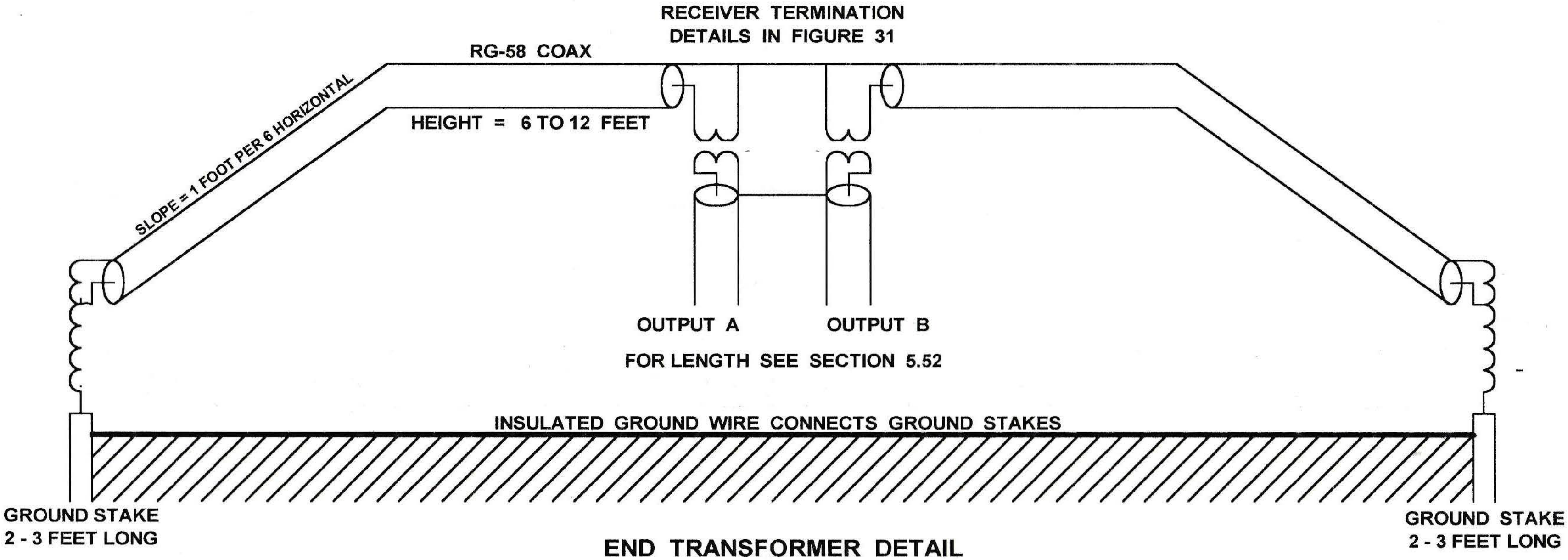


Figure 33.

CENTER FED COAXIAL STEERABLE WAVE ANTENNA



END TRANSFORMER DETAIL

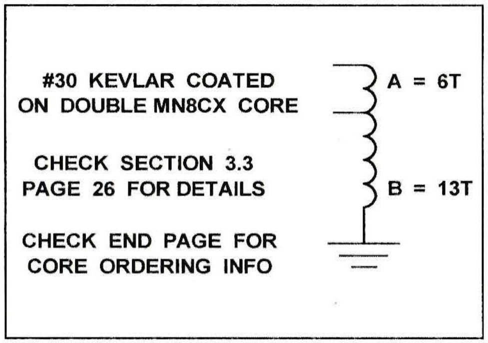


Figure 34.

Parallel ground wires are omitted for snakes and no support posts or structures are necessary. The turns ratio on the end transformers requires some experimentation to optimize performance. The SWA configuration permits easy directivity measurements and null steering. All this from coaxial cable lying on the ground! Because of the high end-to-end loss there would be little to be gained from lengths beyond a half wave. The coax should be well insulated from the ground by running it inside polyethylene water pipe, the larger the diameter the better. The pipe must be sealed to keep water out.

It would be easy to make this antenna disappear by burying it an inch or so under the lawn. Expect better performance in dry, poorly conductive soil or sand. End ground stakes are necessary.

5.56 OFF CENTER FED SWA

The off-center fed variant uses the same components as the center fed SWA and differs only in the placement of the center termination. As long as matching transformers are used at each end to provide a good match, the off-center termination may be placed anywhere along the antenna without altering the directivity or performance. Off-center placement alters the phase relationship between pattern A and pattern B, a problem only when the simple R-L-C null steering circuits are used. The phases can be equalized by lengthening the coax which is connected to the transformer facing the shorter side of the antenna. The length increase required is the difference in electrical length (transmission line mode) between the two sides of the antenna. The difference (if any) between the wave velocities in the coax and the antenna transmission line mode must be taken into account in calculating the amount of compensating coax required.

5.57 THE MICROSWA

The MICROSWA is a highly shortened version of the center fed SWA. The diagram is shown in figure 35. I arbitrarily chose the length of 60 feet because I felt this would fit in many city-size lots. In practice the length can be expanded to fit the available space.

In order to obtain directivity a null steering arrangement must be used with this antenna (see sections 4.5 and 5.6).

The MICROSWA is supported on three 10 foot posts. The end posts are metal pipe (steel or copper) and the center post is 2 inch diameter PVC water pipe. The posts are each cemented into a pair of stacked cement blocks. The cement blocks are then dug in so that the tops of the cement blocks are level with the surface of the ground. The top wire of the MICROSWA is 8 ft 3 in above the surface, the bottom wire is 12 inches below it. The choice of one-over-the-other rather than side-by-side wires was made to facilitate mounting to the poles.

The center termination is mounted on the center post with the coaxial cables taped to the post. The end termination is shown in figure 27. The metal end posts are used to shield the end downleads as shown in figure 27 and described in section 5.35.

W1WCR MICROSWA

OPEN WIRE LINE VERSION

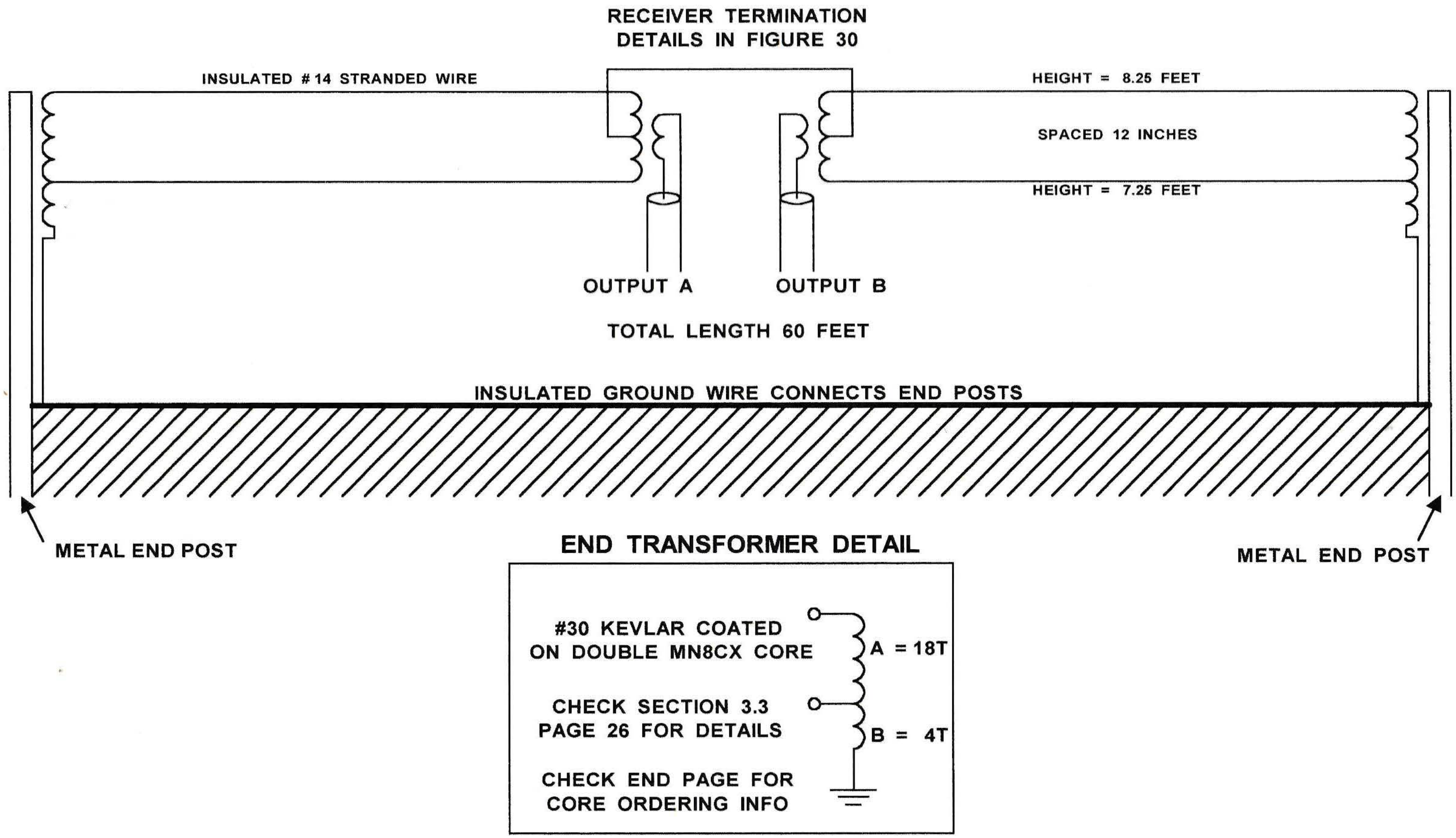


Figure 35.

5.58 THE MICROSLO

The MICROSLO is a radical departure from standard SWA design in its use of a zig-zag slow wave structure to enhance the performance of short antennas. The diagram of a MICROSLO is shown in figure 36. The theoretical basis of this invention is discussed in section 4.6. Indications are that the MICROSLO will replace the MICROSWA in most applications.

The design in figure 36 consists of a 70 foot structure containing seven equal size zig-zags with a base length of 10 feet per zig-zag. A total of 120 feet of wire is used in the zig-zag structure, resulting in an overall wave velocity factor of .58.
If the 70 foot length is divided by 120 the result is also approximately .58.

Another departure from the ordinary design is that the feed points are at opposite ends. This avoids the complexity of constructing a two wire zig-zag. By constructing the antenna out of coaxial cable a center fed version would be practical.

A short piece of grounded wire is shown taped to the antenna at each end to provide shielding in order to move the virtual termination up to the center-line of the zig-zag structure.

The upper tips of my MICROSLO are suspended by tying with lacing twine to an overhead wire broken into short pieces with egg insulators. Lacing twine is used to tie the bottom tips to the ground wire.

Performance on 160 meters can be improved by doubling the length to 14 sawteeth. Other dimensions should not be changed.

5.6 NULL STEERING CIRCUITS

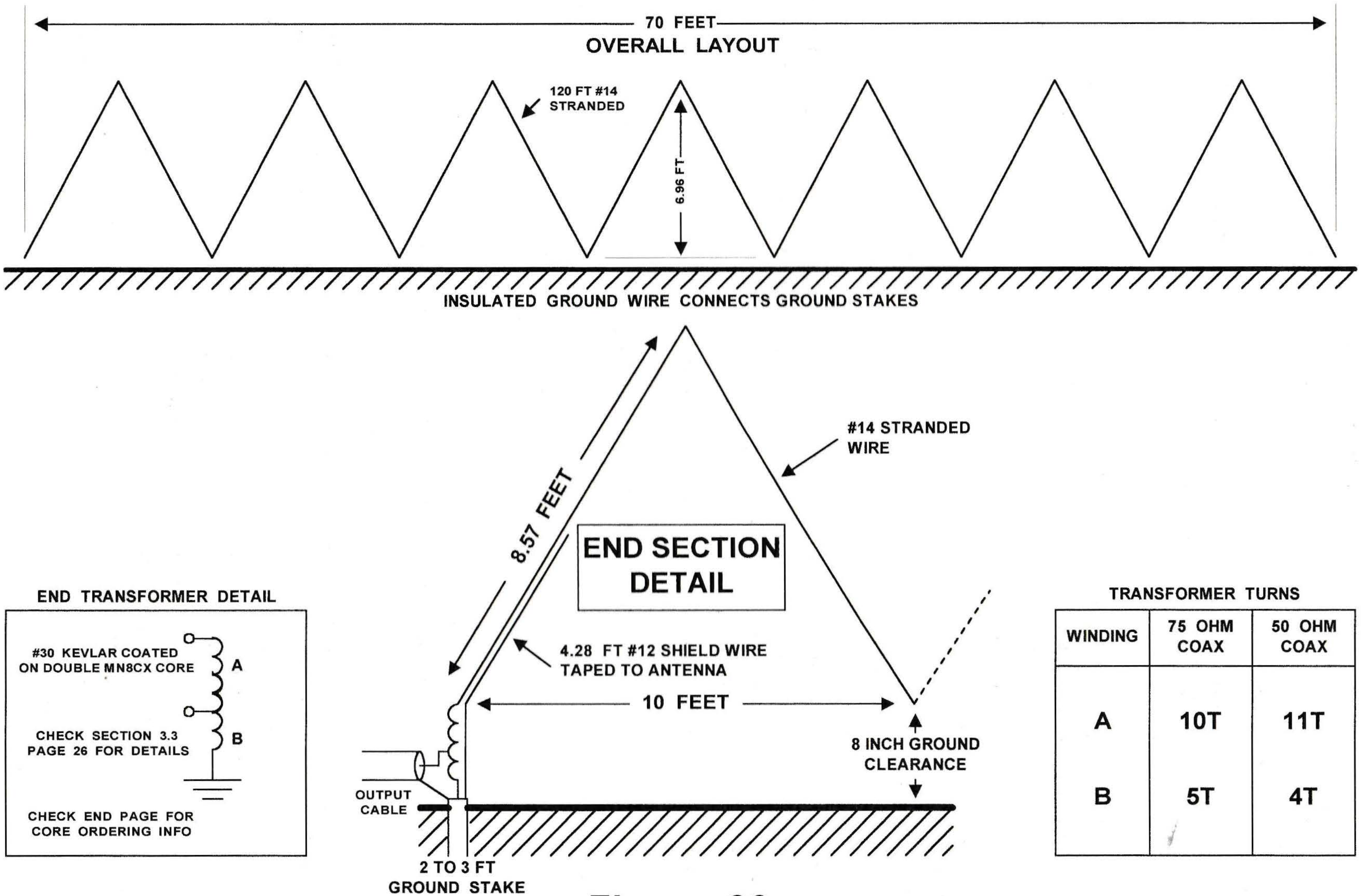
Three null steering circuits are presented. The reflection scheme, the simplest, was used by H. H. Beverage in his original antennas. In the original Beverage papers it is referred to as "damping". The second scheme, subtraction, uses virtually the same components as the first, but provides null steering over a wider range of angles. The third scheme, is called "improved" because it can provides a phase shift within the entire 0 to 360 degree range.

5.61 BY REFLECTION

This is a series connected R-L-C circuit which provides a controlled mismatch to reflect part of the pattern B signal into the pattern A output (and vice versa). Both amplitude and phase of the reflection can be controlled by adjusting the resistance and the variable capacitor shown in figure 37.

With the DPDT switch in the position shown in figure 37 the circuit is ready to null on the backlobes of pattern A (connected to the receiver). The neutral condition for the R-L-C series circuit occurs when L and C are resonant and
R = Zo. For 50 ohm coax R = 50 ohms results in a matched condition resulting in zero reflection and no null steering. If R is greater than 50 ohms an in-phase reflection will result. If R is less than 50 ohms the reflection is out of phase (180 degrees). An extra positive or negative phase shift may be obtained by detuning L-C on the high or low side of the resonant frequency.

W1WCR MICROSLO



TRANSFORMER TURNS

WINDING	75 OHM COAX	50 OHM COAX
A	10T	11T
B	5T	4T

Figure 36.

Thus the amplitude and phase of the reflection can be controlled. Assuming an end fed SWA, the reflected signal must go back down the coax, down the antenna, reflect at the end transformer, travel up the antenna into transformer A where it is now superimposed on the pattern A signal. The reflected signal sustains extra feeder, transformer and antenna losses in its round trip which tend to limit the performance of this null steering method.

The circuit of figure 37 is designed to operate from 1.5 to 7.3 mHz. A larger inductance is required to operate in the broadcast and very low frequency (VLF) bands.

A caveat in the use of the reflection circuit is that the phase of the reflection is proportional to feeder length. The problem can be avoided by making the feeder a multiple of an electrical half wave in length.

I do not recommend using the reflection method because the subtraction method in the following section provides better performance with only a minimal increase in complexity.

5.62 BY SUBTRACTION

The subtraction null steering circuit is shown in figure 38. This circuit null steers by subtracting the pattern B signal from pattern A and vice versa. Direct subtraction avoids the round-trip losses encountered in the reflection method. The phasing is also unaffected by feeder length.

Phase reversal is provided by switching the output of balun B with a DPDT switch. Amplitude is controlled by a potentiometer, R. Phase is controlled by a variable capacitor, C. Unfortunately the setting of C also affects amplitude, hence C and R must be adjusted sequentially in order to converge to a null. The circuit is limited in performance due to the drop-off in amplitude as the phase shift approaches plus or minus 90 degrees. Nevertheless it nulls a wide range of, albeit not all, signals.

The band selector switch selects amateur bands 160, 80, 75 or 40 meters.

5.63 AN IMPROVED NULL STEERING CIRCUIT

The previously described null steering circuits are simple passive networks which have range limitiations in amplitude and phase. The improved null steering circuit shown in figure 39 can provide phase shift over the entire 0-360 degree range without sacrificing amplitude. The circuit provides subtraction nulling as described below.

The lower signal channel (pattern B in figure 39) is split into two branches, XC and XL. The two branches provide respectively a leading and lagging phase shift of 45 degrees resulting in a phase difference of 90 degrees at potentiometers P2 and P3. When P2 and P3 are set to their center positions the output is zero. When P2 is set to its top position its output is maximum and at +45 degrees phase shift. At its bottom position the output is again at maximum, but phase is reversed to +225 degrees. Similarly, P3 top is - 45 degrees and P2 bottom is +135 degrees.

NULL STEERING BY REFLECTION

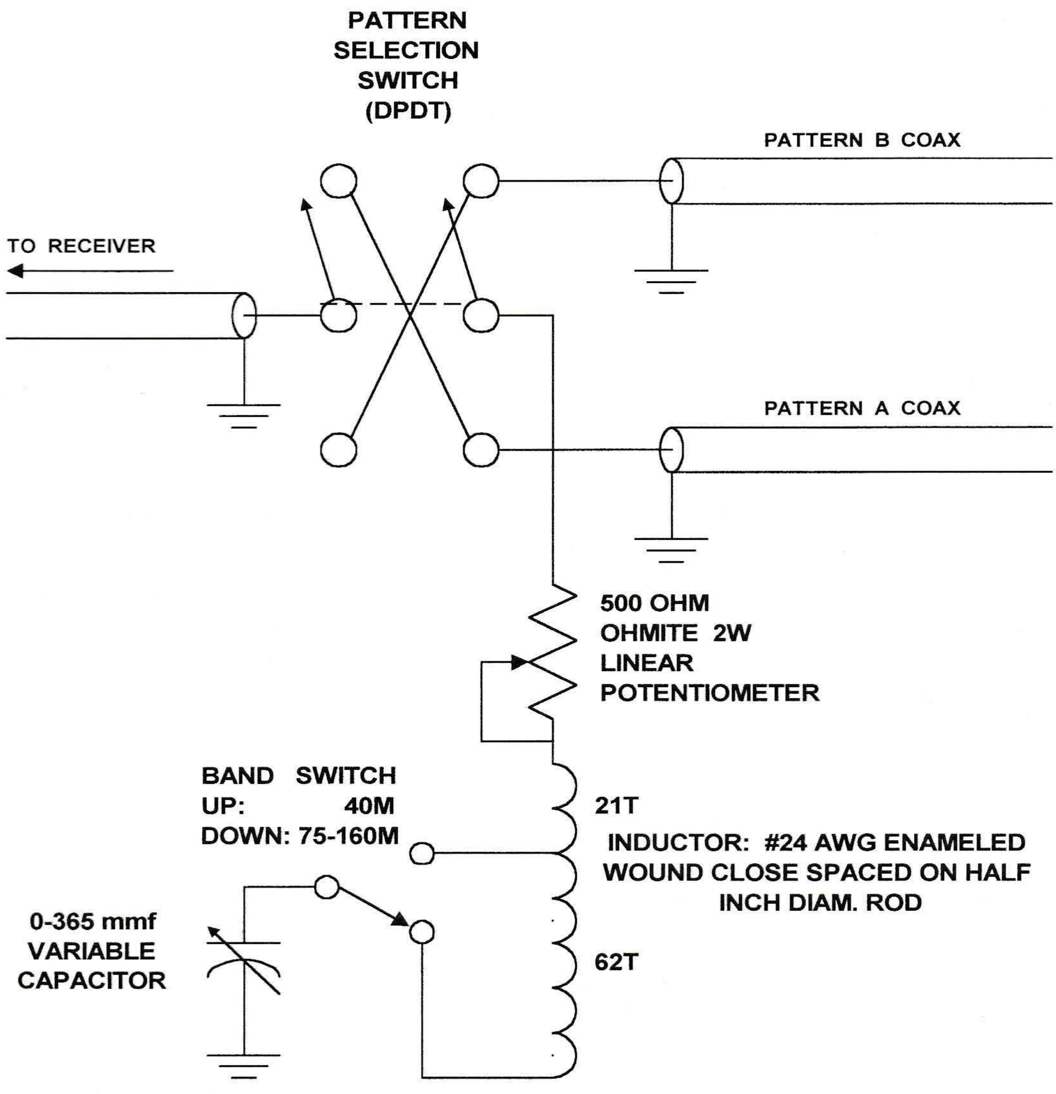
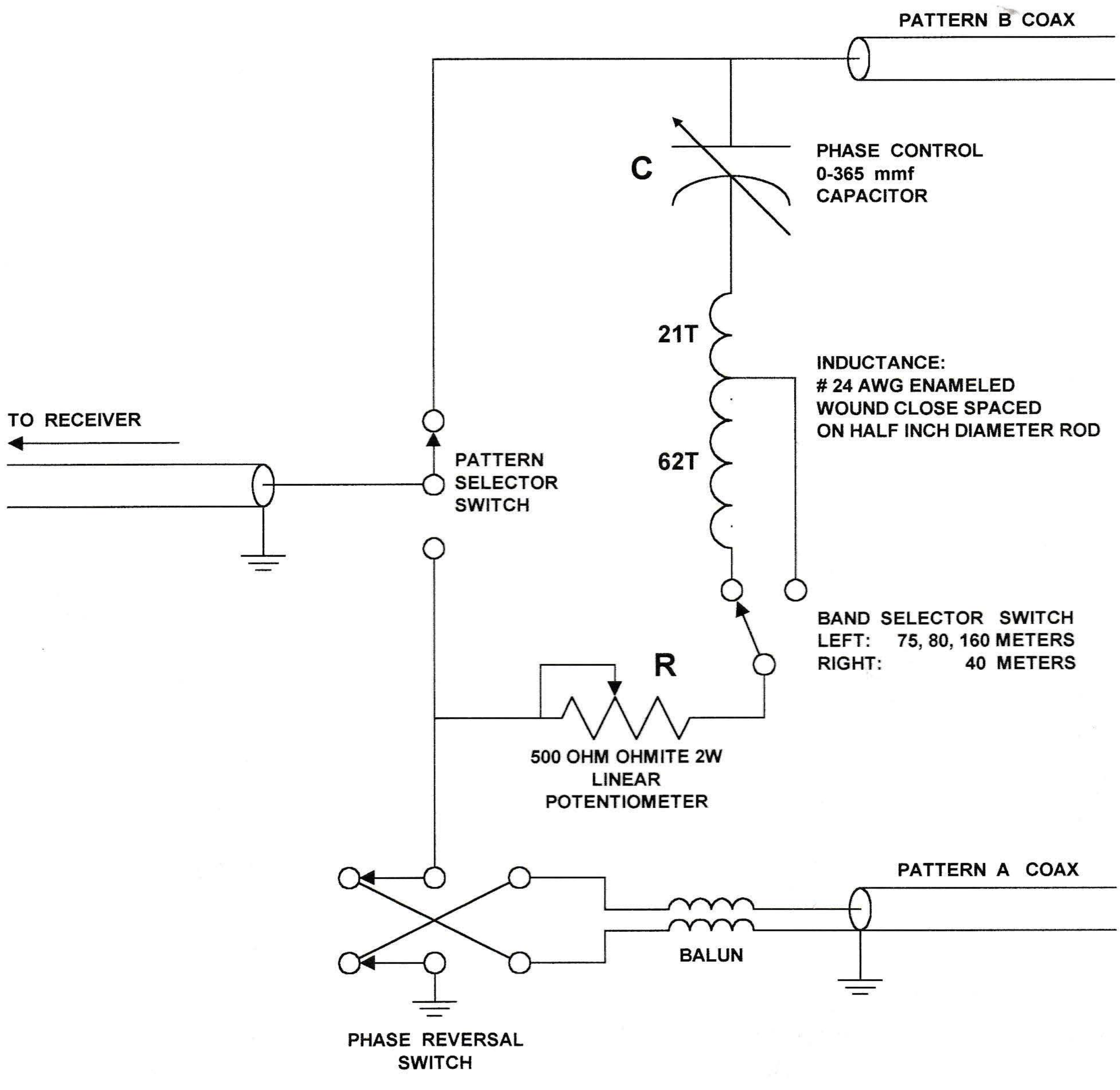


Figure 37.

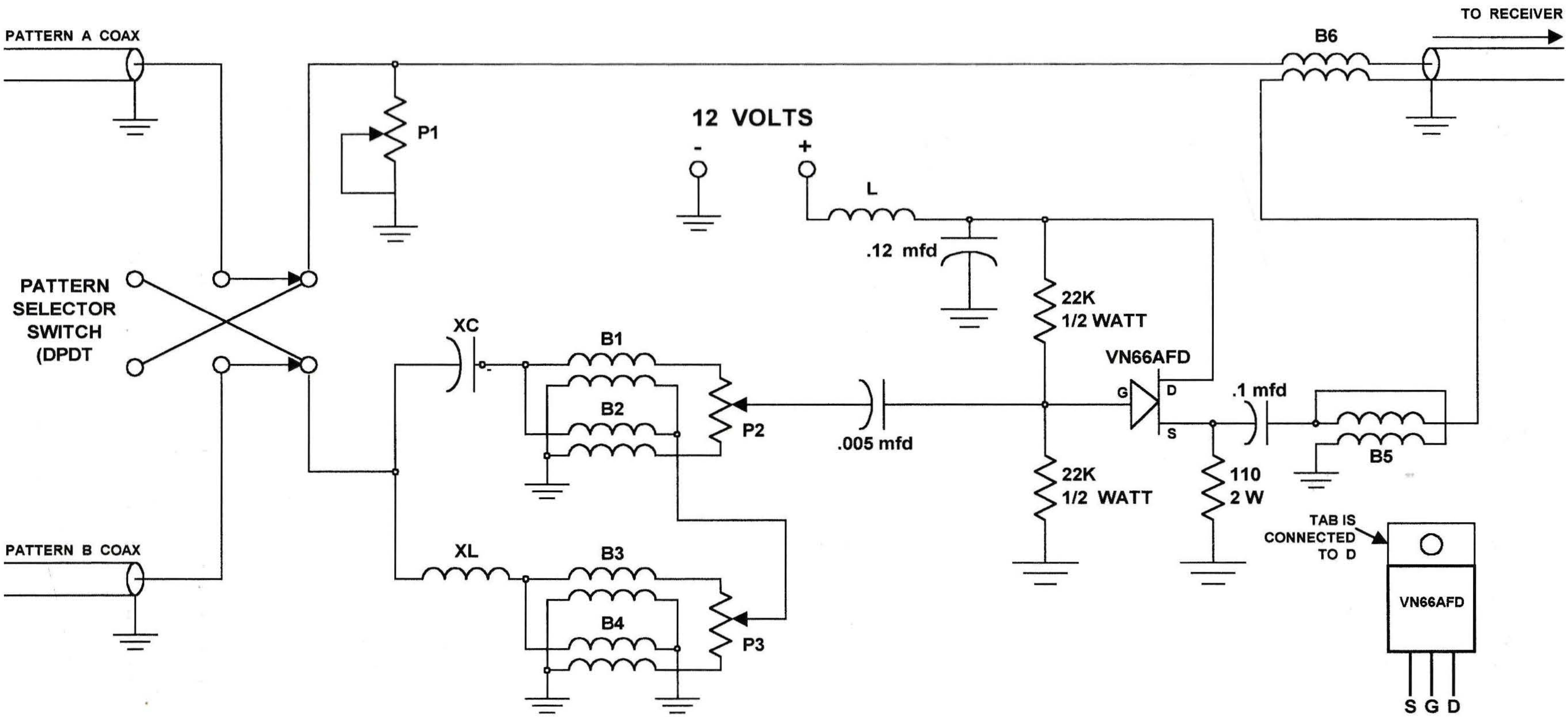
NULL STEERING BY SUBTRACTION



BALUN: ONE-TO-ONE, 12 TURNS TWISTED PAIR OF #30
KEVLAR COATED ON SINGLE MN8CX CORE.
SEE BOTTOM OF PAGE 26 FOR WIRE RECOMMENDATION.
USE RED AND BLUE WIRE TO KEEP TRACK OF POLARITY.

Figure 38.

IMPROVED NULL STEERING CONTROL



ALL BALUNS: B1, B2, B3, B4, B5, B6

15 TURNS #30 KEVLAR COATED TWISTED PAIR WOUND ON SINGLE MN8CX CORE. USE RED AND BLUE WIRE TO KEEP POLARITY CORRECT. SEE BOTTOM OF PAGE 26 FOR WIRE RECOMMENDATION. CORE ORDERING INFORMATION IS ON LAST PAGE.

PARTS INFORMATION

P1	POTENTIOMETER, 500 OHM, OHMITE, 2 WATT, LINEAR
P2,P3	POTENTIOMETERS, 200 OHM, OHMITE, 2 WATT, LINEAR
XC	CAPACITOR, 50 OHMS AT BAND CENTER
XL	INDUCTOR, 50 OHMS AT BAND CENTER
L	12 TURNS HOOK-UP WIRE ON SINGLE MN8CX CORE
VN66AFD	SILICONIX VMOS FIELD EFFECT TRANSISTOR

Figure 39.

Because these outputs are connected in series the resulting vectorial combinations can produce any phase shift over the 0-360 degree range at zero to maximum amplitude.

A VMOS FET is used as a source follower to provide a high impedance load for the phase shifter and to drive the receiver balun, B6, with a low source impedance. Pattern A and B signals are combined in B6 which acts as a series combiner.

The Siliconix VN66AFD is a low noise figure power FET. In this circuit it draws about 90 mA. A one inch square of copper or aluminum should be bolted to the drain as a heat sink. The gate of the VN66AFD has a built-in zener surge protector, but it is wise to disconnect the antenna when not in use or during electrical storms to avoid zorching the gate.

All of the baluns, B1 through B6 are identical. B1 and B2 (also B3 and B4) have their inputs connected in parallel and their outputs in series to form a 1:4 balun which provides balanced drive to P2. The input thus presents a 50 ohm resistive load to XC. The combination of the 50 ohm reactance of XC and the 50 ohm resistive input yields a leading phase shift of 45 degrees. In like manner the combination of the 50 ohm reactance of XL and the 50 ohm resistive input yields a lagging phase shift of 45 degrees. The output of B5 is connected in series with its own input to provide a 2:1 voltage step-up. I recommend using red and blue wire in the twisted pair to avoid wiring mistakes.

The power source is an unregulated 12 volt supply, negative side grounded. CAUTION: Power supplies using switching regulators can cause an unacceptable noise rise in the receiver. It is important to use a clean power supply free of switching hash or other noise sources.

The reactances XC and XL should be 50 ohms at the band center. Below in table X I have listed component values for frequencies of general interest.

TABLE X

175 kHz	C = 18200 pf	L = 45.5 micro-Hy
1000 kHz	C = 3200 pf	L = 8.0 micro-Hy
1900 kHz	C = 1700 pf	L = 4.2 micro-Hy
3800 kHz	C = 840 pf	L = 2.1 micro-Hy
7200 kHz	C = 440 pf	L = 1.1 micro-Hy

The inductor and capacitor, when connected in parallel, form a resonant circuit at the design frequency. Once the capacitor is available the inductance can be wound (or unwound) so that it is resonant at the band center by checking the resonant frequency with a grid dipper. If the resonant frequency is too high, add turns. If too low, remove turns, etc.

A self-check can be performed on the unit as follows:

1. Connect receiver and coax A to unit.
2. Disconnect coax B.
3. Set P2 and P3 fully clockwise.
4. Set DPDT switch to position which feeds coax A into phase shifter.
5. Tune receiver to broadcast station or other steady signal.
6. Null out the signal by setting P2 and P3 to the centers of their ranges.

If the null steering control is working properly it will be possible to null the signal into the receiver noise. If you choose the 1900 kHz band center you can use broadcast band stations to check null steering. It is best to do this in the daytime when signals are very steady. Select a station in the 1400 - 1600 kHz range. Coax A and B must be connected. Start with P2 and P3 set at the center of their ranges. Switch the pattern selector switch to the position which results in the lesser signal. Adjust P2 and P3 for minimum signal. If the maximum position of P2 or P3 is reached without a null, then the P1 resistance should be reduced until P2 and P3 null within their ranges. The null should be reached by sequentially adjusting P1, P2 and P3.

During daylight hours low power local broadcast stations can be stably nulled nearly into receiver noise. The nulls on skywave signals tend to be less stable because of arrival angle changes caused by ionspheric changes. Locally generated noise (power line, TV birdie, etc.) can be very stably nulled into receiver noise. Under disturbed propagation conditions when signals are being received by diffuse backscatter it may not be possible to achieve a null at all.

5.7 CONSTRUCTION COMMENTS

Wave antennas can be set up on wooden posts, PVC posts or posts made of other dielectric materials. Trees also make excellent supports, but are seldom aligned in a straight line. Randomly spaced trees on each side of the antenna can be used by connecting short wires transverse to the antenna between trees on alternate sides, then suspending the antenna from the transverse wires on insulators. Insulators can be made out of plastic tubing, plastic rod, etc. Deviations from a straight line can be determined by sighting down-wire from one end, then corrections made by sliding the suspension insulators side-to-side on the transverse wires.

Insulated wire should be used on the antennas. The insulation reduces the effect of precipitation static. A charged snowflake or raindrop hitting a bare wire produces a "pop" in the receiver as it dumps its charge into the wire. On insulated wire the charge merely builds up on the insulation and gradually leaks away causing much less commotion in the receiver.

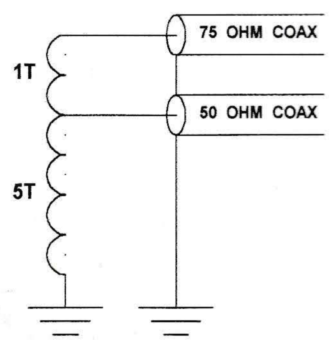
Plastic pill bottles with metal or plastic caps make excellent weatherproof housings for end transformers. I use plastic bottles with a cap diameter of about 1.5 inches. I drill three holes in the cap arranged in an equilateral triangle. In the holes I mount insulated binding posts. The bottoms of the binding posts project inside the bottle. The three leads on the end termination transformer are

soldered to the bottoms of the binding posts. The entire arrangement weighs only about 1.6 oz. The bottle can be taped to a post or support wire or it can be suspended on its connecting wires.

I use small metal boxes to house receiver terminations. On the end fed SWA the box is bolted onto the ground stake. On the center fed it is bolted to a 2 inch diameter PVC post at antenna height.

All of the null steering circuits should be constructed in a shielded box. If the coax is disconnected at the antenna after the system is set up, leakage signals should be down in the receiver noise. Sources of stray leakage such as single-shield coax, leaky receivers, signals entering the receiver or null steering control via a power line or power supply must be eliminated.

The 75 ohm hardline used in cable TV systems make an excellent low loss feeder for SWA's. It is particularly helpful in long runs and can sometimes be purchased at minimum cost as scrap from cable TV companies. If you wish to convert to 50 ohms at the receiver end, use a simple autotransformer wound on two stacked MN8CX cores.



USE #30 KEVLAR COATED
ON DOUBLE MN8CX CORE.
CHECK PAGE 26 BOTTOM
FOR WIRE RECOMMENDED.
CHECK END PAGE FOR
CORE ORDERING INFO.

6 STEERABLE WAVE ANTENNA OPERATION

The first step in operating the wave antenna is to check the receiver for signal leakage. On some older communications receivers it is possible to hear broadcast stations with the antenna disconnected. Such leaky receivers dilute the directivity of wave antennas and should be avoided.

Null steering proceeds as follows:

1. Select an interfering signal with which you wish to share the frequency. This may be a broadcast station, TV birdie, power line hash, etc.
2. Flip the pattern selector switch to the direction which results in the weakest signal. This should be done with null steering disabled. (On the reflection and subtraction null steerers C is set to minimum, on the improved circuit set P2 and P3 to center position.) Watch the S-meter to determine weakest signal. In the absence of an S-meter the AGC should be switched to manual and the

comparison made by judging audio intensity.

3. Sequentially adjust the null steering controls until the amplitude of the interference is minimized. In the reflection circuit (figure 37) only the variable capacitor and potentiometer are involved. In the subtraction circuit the phase reversal switch, R and C are involved. In the improved circuit P1, P2 and P3 are adjusted.

One of the nice features of the SWA is that you can continuously check your nulling effectiveness by flipping the pattern selection switch back and forth while watching your S-meter. The effectiveness of the antenna can be instantly checked using your receiver as a measuring instrument.

The degree and stability of the null depend upon the signal propagation mode, propagation conditions, antenna length and stray pick-up from nearby antennas and structures. The range of nulling capability varies from nulling signals down to receiver noise to virtually ineffective nulling or directivity. Here is a list of signal types and conditions listed in order of decreasing nullability.

1. Local broadcast stations (550-1600 kHz), daylight propagation. These can be nulled into receiver noise. Often a more distant co-channel station can be copied after the local signal is nulled out. The null is very stable because of the stability of the signal arrival angle. The MICROSWA and MICROSLO are particularly effective on broadcast stations.
2. TV birdies, power line noise. These can be usually nulled into receiver noise day or night provided that they come from a single source. This feature is extremely effective for operation on the 160-190 kHz experimental band where light dimmer noise can destroy reception.
3. Low arrival angle skywave signals. These occur under long skip conditions (critical frequency below operating frequency), e.g., night-time 7 mHz signals typically. It is possible to null 40 meter band propaganda stations by 30 dB or more under long skip conditions. This allows U.S. amateur radio operators to share the channel with the broadcasters. The null on skywave signals is generally unstable because the arrival angle changes continuously as a result of ionospheric variations.
4. High arrival angle skywave signals. These include night-time broadcast band (550-1600 kHz), night-time 160 meter signals, daytime 40 and 75 meter signals and short skip night-time 75 meter signals. The inherent FBR of the SWA is lower at high arrival angles, but the arrival angle is often stable enough to maintain nulls of 15-30 dB. This is useful in DX listening on the broadcast band, 160 meters and 75 meters where much of the local QRM is strong and high angle.
5. Multipath skywave signals. The simultaneous arrival of a signal via single, double and triple or more hops can cause a continuous wide angle fluctuation in arrival angle. Null steering effectiveness is greatly reduced under such conditions. The condition is usually accompanied by severe fading due to phase interference between paths.

6. Static. Compared to a non-directional antenna a SWA can provide some discrimination against static and in isolated circumstances a substantial rejection of static. Static generally arrives over a wide range of angles. Under conditions where the antenna is surrounded by static sources the SWA provides some advantage by attenuating static over a range of arrival angles in the reverse direction. This may amount to 1 or 2 dB. When the static generating storm is located at a distance in a definable direction, then it may be possible to null steer on the storm. I have found that here in New Hampshire the SWA has been useful in reducing summer static on 75 meters. When the static arrives primarily from the southwest the SWA will often reduce the static on European signals by one or two S-units. A similar effect is noted on the 160 meter band. The static reduction on 160 is rarely as effective as on 75 possibly because the higher propagation angles on 160 reduce the effective FBR of the SWA. Null steering on static is often a lesson in frustration since each burst arrives from a different angle. If the static is reasonably continuous it is easier to attempt nulling. Sometimes it takes only a few dB of suppression to salvage a QSO in heavy static.

7. Scattered skywave. Auroral scattering or other wide angle inospheric forward or backscatter can make a SWA seem virtually non-directional. This can occur during solar flare activity. Signals are often weak, fluttering and fading. There may be an echo effect and a hollow sound to the audio.

Antenna length and end-to-end loss affect nulling stability. The longer and lossier the antenna the less stable the null. Because of this it is sometimes nice to have a short SWA handy to handle some of the more obnoxious nulling problems which are known to arise on amateur radio.

Under weak or marginal signal conditions the null steering controls can be adjusted for MAXIMUM SIGNAL. This should be kept in mind as an option when the sun is rising and the band is dropping out on a rare DX signal.